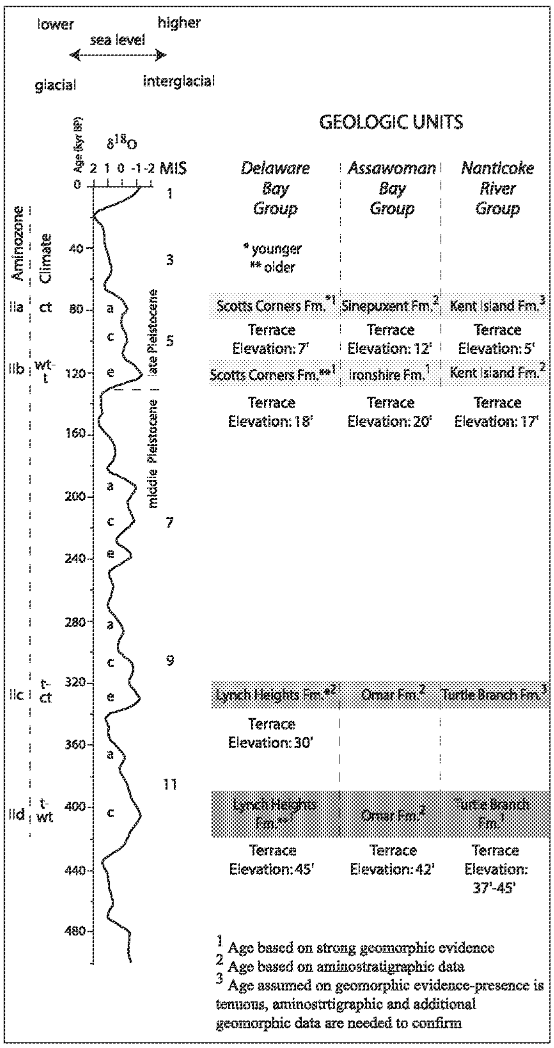
State of Delaware
DELAWARE GEOLOGICAL SURVEY
John H. Talley, State Geologist

REPORT OF INVESTIGATIONS NO. 76

STRATIGRAPHY, CORRELATION, AND DEPOSITIONAL ENVIRONMENTS OF THE MIDDLE TO LATE PLEISTOCENE INTERGLACIAL DEPOSITS OF SOUTHERN DELAWARE

By
Kelvin W. Ramsey



University of Delaware
Newark, Delaware
2010

ED_005024_00000664-00001

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STRATIGRAPHY, CORRELATION, AND DEPOSITIONAL ENVIRONMENTS OF THE MIDDLE TO LATE PLEISTOCENE INTERGLACIAL DEPOSITS OF SOUTHERN DELAWARE

ABSTRACT

Rising and highstands of sea level during the middle to late Pleistocene deposited swamp to nearshore sediments along the margins of an ancestral Delaware Bay, Atlantic coastline, and tributaries to an ancestral Chesapeake Bay. These deposits are divided into three lithostratigraphic groups: the Delaware Bay Group, the Assawoman Bay Group (named herein), and the Nanticoke River Group (named herein). The Delaware Bay Group, mapped along the margins of Delaware Bay, is subdivided into the Lynch Heights Formation and the Scotts Corners Formation. The Assawoman Bay Group, recognized inland of Delaware's Atlantic Coast, is subdivided into the Omar Formation, the Ironshire Formation, and the Sinepuxent Formation. The Nanticoke River Group, found along the margins of the Nanticoke River and its tributaries, is subdivided into the Turtle Branch Formation (named herein) and the Kent Island Formation.

Delaware Bay Group deposits consist of bay-margin coarse sand and gravel that fine upward to silt and silty sand. Beds of organic-rich mud were deposited in tidal marshes. Near the present Atlantic Coast, the Delaware Bay Group includes organic-rich muds and shelly muds deposited in lagoonal environments.

Assawoman Bay Group deposits range from very fine, silty sands to silty clays with shells deposited in back-barrier lagoons, to fine to coarse, well-sorted sands deposited in barriers and spits.

Nanticoke River Group deposits consist of coarse sand and gravel that fine upward to silty clays. Oyster shells are found associated with the clays in the Turtle Branch Formation. Organic-rich clayey silts were deposited in swamps and estuaries. Well-sorted fine sands to gravelly sands were deposited on beaches and tidal flats on the flanks of the ancestral Nanticoke River and its tributaries.

The Lynch Heights, Omar, and Turtle Branch Formations are age-equivalent units associated with highstands of sea level,which occurred at approximately 400,000 and 325,000 yrs B.P. (MIS 11 and 9, respectively). The Scotts Corners, Ironshire, Sinepuxent, and Kent Island Formations are age-equivalent units associated with highstands of sea level, which occurred between 120,000 and 80,000 yrs B.P. (MIS 5e and 5a, respectively).

INTRODUCTION

It has been 36 years since publication of Jordan's (1974) summary of the Pleistocene deposits of Delaware. Jordan considered the Pleistocene deposits to be glacial outwash sediments of the Columbia Formation covering most of Delaware that graded down dip into the Omar and Beaverdam Formations. The estuarine Omar Formation was recognized in the southeast corner of the state south of Indian River, and scattered dune and shoreline deposits stretched from the Nanticoke River in an arc across the state toward Milton. The Beaverdam Formation was considered to be a down-dip, subsurface facies of the Columbia Formation. Owens and Denny (1979a) indicated that the geology was more complex than that of Jordan (1974) in southern Delaware with two additional estuarine units found seaward of the Omar Formation, the Ironshire and Sinepuxent Formations, which trended parallel to the present Atlantic Coast and Delaware Bay. In their mapping, the Beaverdam Formation, rather than the Columbia Formation, was the most extensive unit in the center of the Coastal Plain of southern Delaware. Demarest et al. (1981) examined the estuarine deposits of southeastern Delaware and proposed a series of seaward-stacked barriers within the Omar Formation. More recent geologic mapping in Kent and Sussex Counties (Ramsey, 1993, 1997, 2001, 2003, 2007; Andres and Ramsey, 1995; Andres and Howard, 2000; Andres and Klingbeil, 2006) has revealed a great deal of complexity in the surficial geology of southern Delaware.

Purpose and Scope

The purpose of this publication is to update the stratigraphic framework and correlation of the deposits associated with middle to late Pleistocene interglacial highstands of sea level in southern Delaware (Fig. 1). Two new lithostratigraphic groups and one new formation are defined. The geology presented in this report provides a framework for detailed geologic mapping of southern Delaware, which includes the distribution of sandy and clayey deposits related to coastal environments associated with the rise and highstands of sea level. Understanding the geologic history of these deposits is important because these sediments are the pathway for the distribution, transmission, and quality of groundwater that is used for agriculture, private water supply, and industrial purposes in southern Delaware.

Eolian, swamp, and Carolina Bay deposits of latest Pleistocene to early Holocene age (Ramsey, 1997, 2007), dunes (Ramsey, 2007), the Cypress Swamp Formation (Andres and Howard, 2000; Andres and Klingbeil, 2006), and swamp to shoreline deposits associated with the Holocene rise in sea level (Kraft et al., 1987) are not discussed in this report other than how they are differentiated from the interglacial deposits that they overlie. However, these deposits, which can be mapped separately, are an important part of the geologic history of the Delmarva Peninsula and have different geologic origins than the interglacial deposits that are the focus of this paper.

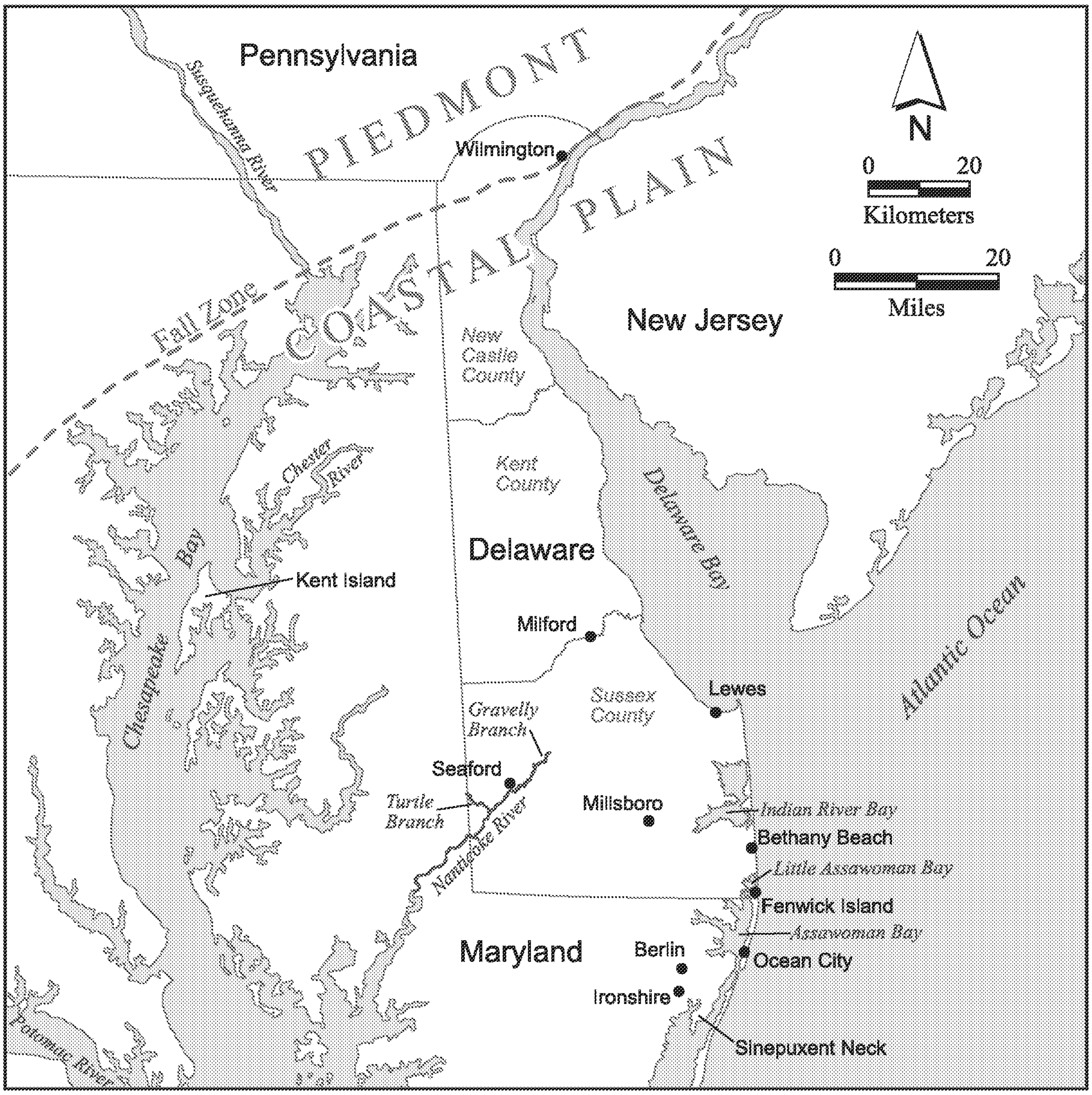

Figure 1. Regional map showing the Delaware and Maryland portions of the Delmarva Peninsula between Chesapeake Bay and the Delaware Bay.

Pleistocene Geochronology

The Pleistocene was historically subdivided into periods of glaciations (glacial) and warm periods between glaciations (interglacial) that were named for geographic locations where related glacial and interglacial deposits were best recognized and described. In North America, the last and penultimate glacial epochs were named the Wisconsinan and Illinoian, respectively. The interglacial epoch between the two glaciations was named the Sangamon. These names then were applied as divisions of time to units not directly affected by glaciation, especially to interglacial sea-level high-stand deposits (Bowen, 1978). The terms are still used by those who study Pleistocene deposits, but are becoming less common in usage outside the areas of glacial maxima. The terms Wisconsinan and Illinoian are still widely used for the last and penultimate glaciations. The term pre-Illinoian is now used to refer to all glaciations prior to the Illinoian with numerical designation to differentiate between glacial events (Richmond and Fullerton, 1986).

The Pleistocene is now divided into early, middle, and late (Table 1). The boundary between the early and middle Pleistocene has been established as the time of the last polarity reversal (Matuyama/Brunhes boundary) at 780 ka (Lisiecki and Raymo, 2005). The boundary between the middle and late Pleistocene is the beginning of the last interglacial at 128 ka (Cutler et al., 2003). The end of the Pleistocene and its boundary with the Holocene has traditionally been placed at 10,000 yrs B.P. (Richmond and Fullerton, 1986), but recently a new formal boundary has been proposed at 11,700 yrs b2 k (b2 k= before AD 2000) (Walker et al., 2009).

With the advent of the recognition of stages based on oxygen isotopes from benthic foraminifera in marine deposits that record the fluctuations of glacial and interglacial periods, the use of stage numbers has become the standard chronology for Pleistocene marine and coastal deposits (Richmond and Fullerton, 1986). The stages begin at 1 for the present interglacial interval (Holocene) and increase in time with odd numbers representing interglacial intervals and even numbers

Table 1. Pleistocene marine isotope stages.

		Marine Oxygen Isotope Stage *		Age (kyrs B.P.)
HOLOCENE		1		0- ~12
PLEISTOCENE	Late	2	Wisconsinan glaciation	13-24
		3		24-64
		4		64-76
		5		76-128
		5a		71-85
		5b		85-93
		5c		93-105
		5d		105-113
		5e		113-128
	Middle	6	Illinoian glaciation	128-185
		7		185-245
		8		245-293
		9		293-339
		10		339-370
		11		370-425
		12-19		425-780
	Early			780-2600

*Stage 1: Walker et al., 2009; Stages 2-5, 5a-5e: Cutler et al., 2003; Stages 6-11: Tzedakis et al., 2001; early/middle Pleistocene boundary: Lisiecki and Raymo, 2005; early Pleistocene range: Walker and Geissman, 2009.

representing glacial intervals (Table 1). Because these stages are related to climatic episodes, the time assigned to each marine isotope stage (MIS) varies slightly depending on the geographic location from which the isotopic data are collected. As more precise data become available, the age of the MIS boundary is adjusted to reflect the new data. The ages of the MIS boundaries and the middle and late Pleistocene boundaries used in this report follow those listed in Table 1.

Acknowledgments

This work builds upon the experience and knowledge of those who have worked in the Atlantic Coastal Plain. Initial work by William Rasmussen set the stage for those who have come later. Robert Jordan and Jim Owens established much of the Quaternary stratigraphic framework for Delaware and adjacent Maryland, respectively. Geologic mapping in Virginia by Gerald Johnson, Rick Berquist, Wayne Newell, and Robert Mixon developed a model for the relationship between sea level, fluvial and estuarine deposition, and geomorphology. Johan Groot and Peter McLaughlin of the DGS have contributed valuable information regarding the palynology of the Pleistocene units. A. Scott Andres of the DGS conducted much of the initial surficial geologic work in southern Delaware related to hydrogeologic investigations that preceded the geologic mapping that is the basis of this report. John Wehmiller and his students have been instrumental in understanding the Quaternary aminostratigraphy of the region. John Wehmiller is thanked for valuable discussions over the years regarding Quaternary stratigraphy and sea-level issues. The author would especially like to acknowledge the drilling assistance of Roland Bounds and Paul S. McCreary of the Delaware Geological Survey and Charles Smith who has been always willing to provide technical assistance when needed. A number of students from the University of Delaware assisted in field work and sample processing, and their help and enthusiasm have been greatly appreciated. Lillian Wang of the DGS provided assistance with GIS mapping and with drafting the figures. Stefanie Baxter assisted with the figures and spent many hours editing this manuscript. Much of this work has been funded through the StateMap Program, a cooperative effort of the Association of American State Geologists and the U.S. Geological Survey. John Wehmiller and Wayne Newell reviewed an earlier version of this manuscript and A. Scott Andres and Peter McLaughlin reviewed this version.

LITHOSTRATIGRAPHY

Pre-middle Pleistocene Surficial Deposits of Southern Delaware

Although not the focus of this report, a brief discussion of older deposits that underlie the interglacial deposits of southern Delaware (the Beaverdam and Columbia Formations) is included to aid in differentiation of the deposits and to provide a geologic context for interglacial deposition. The Walston Formation (Hansen, 1966) is present in southernmost Delaware (Fig. 2) but is not in stratigraphic contact with the interglacial deposits and is not discussed in this report.

Beaverdam Formation

Original Reference: In southern Delaware (Fig. 2), the most areally extensive surficial deposit in contact with the interglacial deposits is the Beaverdam Formation presumed to be late Pliocene in age (Ramsey, 1992). The Beaverdam Formation has also been referred to as the Beaverdam Sand (Rasmussen and Slaughter, 1955; Owens and Denny, 1979a) or as the Beaverdam facies of the Salisbury Formation (Hansen, 1966). The Beaverdam Formation is the accepted usage in Delaware (Jordan, 1962, 1974; Andres and Ramsey, 1995, 1996; Ramsey, 2001, 2005; Andres and Klingbeil, 2006). Jordan (1974) considered the Beaverdam to be a down-dip, estuarine facies of the Columbia Formation.

Type Area: The Beaverdam Formation is exposed along Beaverdam Creek in Wicomico County, Maryland (Rasmussen and Slaughter, 1955).

Type Section: None designated.

Description: The Beaverdam Formation is a predominantly sandy, heterogeneous unit ranging from very coarse sand with pebbles to silty clay. The sands are typically feldspathic. The predominant lithologies are white to mottled light-gray and reddish-brown, silty to clayey, fine to coarse sand. Laminae and beds of very coarse sand with pebbles to gravel are common. Laminae and beds of bluish-gray to light-gray silty clay are also common. In a few places near the land surface, but more commonly in the subsurface, beds ranging from 2 to 20 feet thick of finely laminated, very fine sand and silty clay are present (Jordan, 1962, 1974; Andres and Ramsey, 1995, 1996; Ramsey, 2001, 2005; Andres and Klingbeil, 2006).

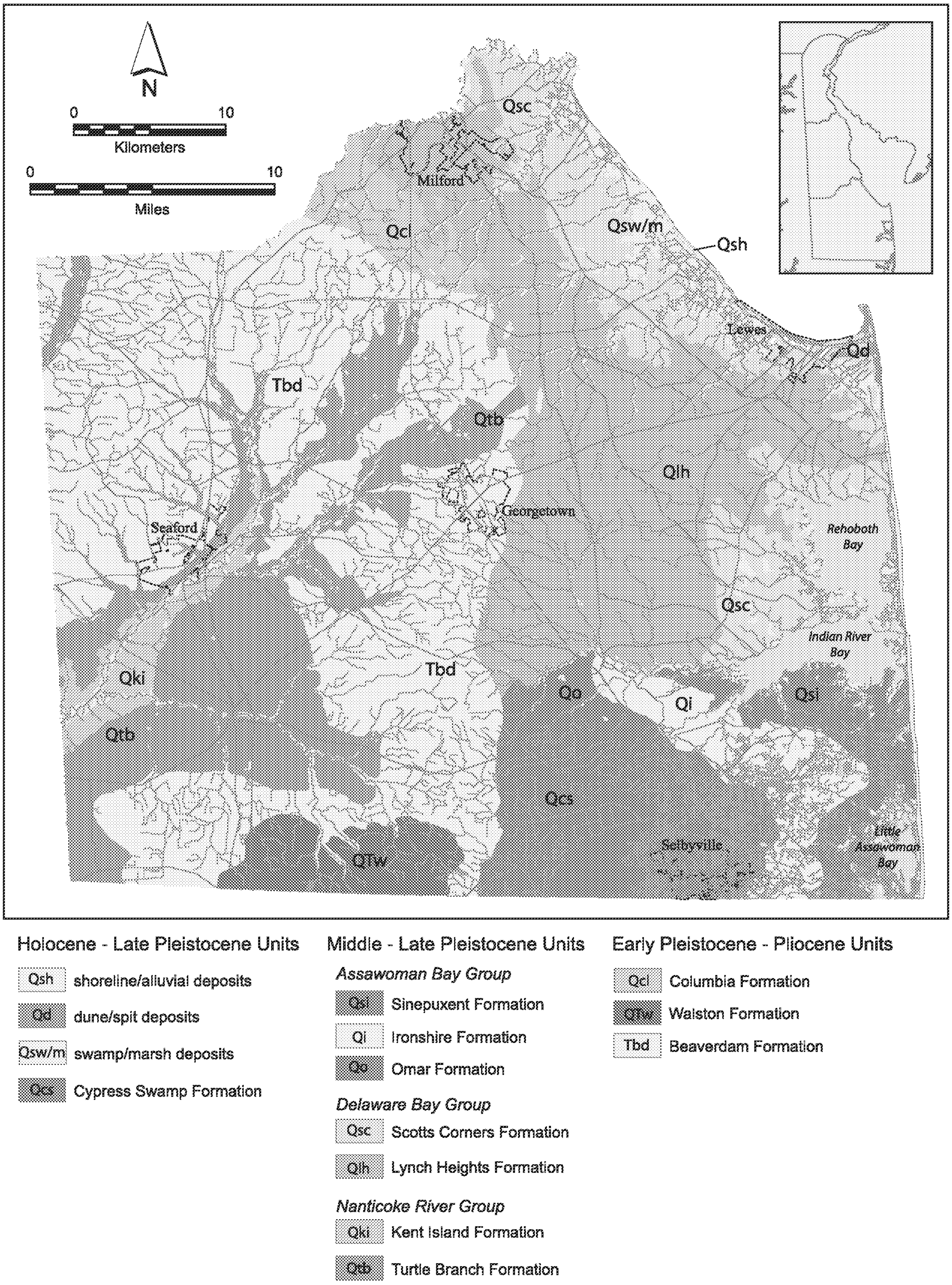

Figure 2. Generalized geologic map of Sussex County showing the distribution of the late Pleistocene and older units with an overlay of stream networks. The Cypress Swamp Formation (Qcs) is modified from Andres and Klingbiel (2006). The stream network is discussed later in this report.

The sands of the Beaverdam Formation have a white silt to clay matrix that gives drill cuttings a milky appearance. This white, fine matrix is the most distinguishing characteristic of the unit and readily differentiates the Beaverdam Formation from the Columbia Formation and the younger interglacial and late glacial to recent deposits. The characteristic white matrix is similar to silt-sized particles derived from fine-grained saprolite of metamorphic and igneous rocks (Wright, 2007), which may indicate a potential Piedmont source area for part of the sediments of the Beaverdam Formation. The gravels of the Beaverdam Formation contain chert and sandstone clasts derived from the Appalachians and a few lithic clasts of Piedmont origin (DGS unpublished data).

Geomorphology: The surface of the Beaverdam Formation is a relatively flat plain ranging between 60 and 45 feet in elevation in southern Delaware. A few erosional remnants of the Beaverdam Formation occur as isolated "hills" rising above the otherwise flat landscape (e.g., Wilson Hill west of Georgetown; Ramsey, 2010).

Depositional Environment: The Beaverdam Formation is interpreted to be a fluvial to estuarine deposit (Owens and Denny, 1979a; Ramsey, 1992, 2007) based on its fining-upward character and on clay drapes and burrows observed in outcrop.

Age: Groot et al. (1990) reported a Pliocene age for the Beaverdam Formation, albeit with little evidence other than a few pollen samples. It overlies a regional unconformity that truncates the St. Marys-Cat Hill-Bethany sequence (Andres, 2004; McLaughlin et al., 2008) and older, up-dip units (Ramsey, 2007, 2010). The lower part of the Cat Hill Formation is late Miocene (McLaughlin, et al., 2008). The upper part of the Cat Hill Formation and the Bethany Formation are in stratigraphic continuity with the lower part of the Cat Hill Formation, but have not yielded fossils useful for dating. Therefore, in Delaware, the Beaverdam Formation is no older than late Miocene in age in southern Delaware.

The coarse-grained clastic sediments of the Beaverdam Formation overlie a regional unconformity that shows significant erosion of all the Miocene and older units of the Delaware Coastal Plain (Ramsey, 2007). Regionally, in the Atlantic Coastal Plain in Virginia, a similar unconformity is located above the early to late Pliocene Yorktown Formation (Dowsett and Wiggs, 1992). The unconformity is regional in extent with coarse clastics overlying and progressively truncating updip the Miocene and Pliocene units of the Virginia Coastal Plain (Mixon et al., 1989; Ramsey, 1992). This regional unconformity above the Yorktown Formation is believed by the author to be contemporaneous with the unconformity beneath the Beaverdam Formation (Ramsey, 1992). Therefore, by regional correlation, the Beaverdam Formation is no older than Pliocene in age.

In northern Delaware, the Beaverdam Formation is truncated by the Columbia Formation, which is considered to be early Pleistocene in age (age discussed below). This indicates the Beaverdam Formation is no younger than early Pleistocene in age. Taking these factors into account, I consider the Beaverdam Formation to be late Pliocene in age, concurring with Owens and Denny (1979a), Groot et al. (1990), and Groot and Jordan (1999), but with the caveat that it could range in age from late Miocene to early Pleistocene.

Columbia Formation

Original Reference: The Columbia Formation was first defined by McGee (1886). Jordan (1962) applied the name in Delaware.

Type Area: The type area for the Columbia Formation was established by McGee (1886) as the District of Columbia.

Type Section: None designated.

Description: The Columbia Formation (Jordan, 1962, 1974; Ramsey, 1997, 2005, 2007; Spoljaric and Woodruff, 1970) is a yellowish- to reddish-brown, fine to coarse, feldspathic, quartz sand with varying amounts of pebbles. It is typically cross-bedded with beds ranging from a few inches to over three feet in thickness. Scattered beds of tan to reddish-gray clayey silt are common. In southeastern Kent County and northeastern Sussex County, the upper 5 to 25 feet of the Columbia Formation commonly consists of grayish- to reddish-brown silt to very fine sand overlying medium to coarse sand. Near the base of the unit throughout its extent, clasts of cobble to small boulder size are found in a gravel bed ranging from a few inches to three feet thick. The gravel fraction consists primarily of quartz with lesser amounts of chert; however, clasts of sandstone, siltstone and shale from the Valley and Ridge Province, and pegmatite, micaceous schist, and amphibolite from the Piedmont Province are also present (Spoljaric and Woodruff, 1970; Jordan, 1974).

Geomorphology: The Columbia Formation occupies a small area in southern Delaware west of Milford and Milton (Ramsey, 1993, 1997, 2001, 2005) (Fig. 2). Its surficial expression is a flat plain with a range of elevations between 55 and 45 feet.

Depositional Environment: The Columbia Formation has been interpreted as being deposited during a series of rapid discharges of water from an ancestral Delaware River (Spoljaric, 1967; Spoljaric and Woodruff, 1970). These sediment-laden discharges eroded pre-existing deposits; coarse sand and gravel carried by the melt water pulses were then deposited as the Columbia Formation (Spoljaric, 1967; Spoljaric and Woodruff, 1970). Analysis of cores from central Kent County indicates that the Columbia Formation unconformably overlies the Beaverdam Formation (Ramsey, 2007). Erosion associated with deposition of the Columbia Formation appears to have completely removed the Beaverdam Formation in most of New Castle County (Ramsey, 2005), although there may be remnants of the Beaverdam underneath the Columbia Formation in the subsurface that cannot be readily differentiated due to the textural similarities of the two units.

The Columbia Formation fills a topographically irregular unconformity overlying units from Miocene to Pliocene in age and is anywhere from 10 to 50 feet thick (Ramsey, 2007). It has been interpreted as primarily fluvial glacial

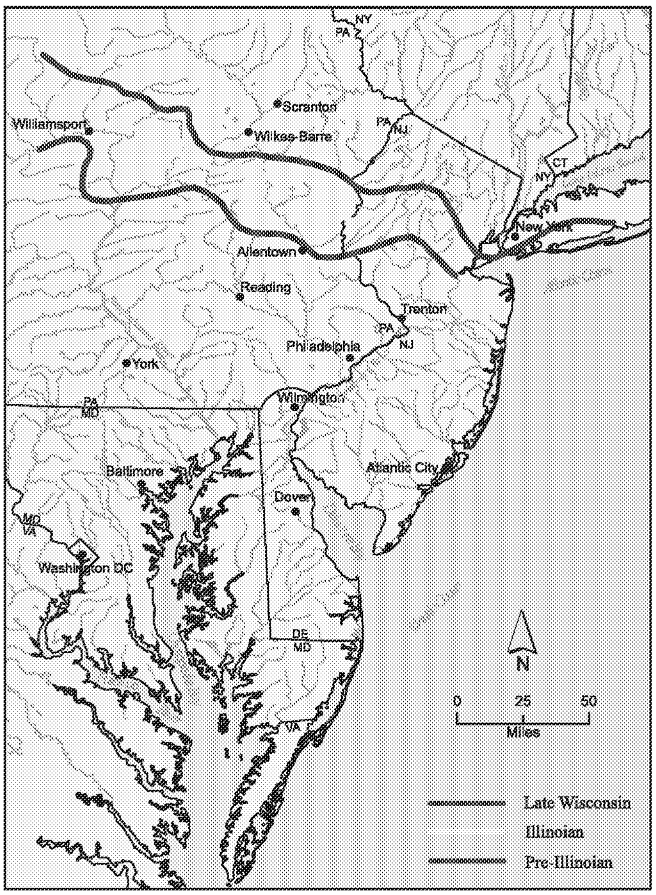

Figure 3. Limits of Pleistocene glaciation based on location of tills and moraines (modified from Braun, 2008).

outwash sediment based on sedimentary structures and large clasts with glacial striations (Jordan, 1964; Spoljaric, 1967; Ramsey, 1997). Pollen from the clayey silt beds from within the Columbia Formation have been interpreted as cold climate flora of middle Pleistocene age (Groot and Jordan, 1999). The Pleistocene pollen data for this region, however, are relatively inconclusive in terms of absolute age control and have not been correlated with any age-constrained deposits.

Age: The age of the Columbia Formation, like that of the Beaverdam Formation, is speculative due to the lack of definitive fossils and can only be estimated by the age of overlying and underlying dated strata. The Columbia Formation is overlain by the Lynch Heights Formation, which is interpreted (this report) as being pre-Illinoian, middle Pleistocene age (approx. 400 ka and 250 ka yrs). The Columbia Formation overlies the Beaverdam Formation, which could range from late Miocene to late Pliocene in age, but is considered late Pliocene in this report. Assuming that the Columbia Formation is glacially-derived sediment deposited by significant meltwater event(s) and that it is pre-Illinoian in age, it may be related to pre-Illinoian-dated glacial deposits in the drainage basin of the Delaware River. Pre-Illinoian glacial deposits have been mapped in the Delaware drainage basin in Pennsylvania (Fig. 3) with at least one yielding reversed polarity measurements which indicates that it is older than 770 ka (Braun, 2008). Similar deposits in New Jersey have been suggested to be correlative with the pre-Illinoian till in Pennsylvania or to be even as old as late Pliocene (2 Ma) (Stanford, 1997). If the Columbia is glacial outwash related to melting of a pre-Illinoian ice sheet, then it is no older than early Pleistocene in age on the basis of correlation with glacial deposits in Pennsylvania. Because the pollen from the Columbia Formation does not include exotic taxa forms that are no longer found in this region (Groot and Jordan, 1999; Groot, 1991), it is less likely that it is as old as late Pliocene.

Middle to Late Pleistocene Interglacial Deposits of Southern Delaware

The middle to late Pleistocene interglacial deposits of southern Delaware described in this report consist of heterogeneous lithologies. The formations were deposited in environments such as an estuarine shoreline, back-barrier lagoon, or other intertidal settings that consist of a variety of lithologies (e.g., fine sand, gravelly sand, clayey silt with shells). When grouped together, these lithologies form a coherent unit that is geologically consistent both horizontally and laterally with the environments in which they were deposited. The variety of lithologies and associated depositional environments of the Holocene deposits along Delaware's coast (Kraft et al., 1987) is a good model for the middle to late Pleistocene interglacial units of southern Delaware.

The geologic history of the interglacial deposits in southern Delaware can be attributed to the cycles of sea-level change that occurred during the Pleistocene. During glacial lowstands of sea level, incision of stream valleys occurred. As sea level rose, these stream valleys were filled and eventually overtopped. During the sea-level highstands, a scarped shoreline developed between the area undergoing deposition and the older, higher deposits inland. As a result, the lithologies of the units are very similar. The lithologic description of the Lynch Heights Formation, for example, does not differ much from that of the Scotts Corners Formation. The two formations were deposited in similar geographic and geologic settings and depositional environments. This similarity poses a handicap in differentiation of adjacent units. Where differentiation of units is not possible, stratigraphic group terminology can be used. For example, the Lynch Heights and Scotts Corners Formations comprise the Delaware Bay Group (Ramsey, 1997), which is composed of a mix of heterogeneous lithologies consistent with deposition along the margins of a large estuary, such as those found along the margins of Delaware Bay. Combining the interglacial deposits into three groups helps form a cohesive understanding of the overall geologic history of the region. The group nomenclature also is of use where individual formations within the group cannot be determined at an individual site or when discussion of the units is on a local or regional scale and the group name suffices in the context of the discussion.

The middle to late interglacial Pleistocene deposits of southern Delaware are subdivided into three lithostratigraphic groups: the Delaware Bay Group (Ramsey, 1997), the Assawoman Bay Group (named herein), and the Nanticoke River Group (named herein). A geologic map of Sussex

County (Fig. 2) shows the distribution of the formations within each group. The Delaware Bay Group, mapped along the margins of Delaware Bay, is subdivided into the Lynch Heights Formation and the Scotts Corners Formation. The Assawoman Bay Group, found south of Indian River, is subdivided into the Omar Formation, the Ironshire Formation, and the Sinepuxent Formation. The Nanticoke River Group, which is mapped in Delaware along the Nanticoke River and its tributaries, is subdivided into the Turtle Branch Formation (named herein), and the Kent Island Formation.

Summary descriptions of each of the middle to late Pleistocene interglacial lithostratigraphic units are given in the following sections. Each of these units vary greatly in lithology over the area of their distribution. The lithologic descriptions incorporate previously published descriptions with those from recent mapping and are intended as a general description of each unit. If a formation was previously defined in another state, a reference section is designated in Delaware and described. In addition to type localities already established, a reference section is designated for each unit in Delaware. Spatial and elevation data for the type and reference sections are shown in Table 2 and locations are shown on Figure 4. The ages of the units given in the following summaries are in terms of approximate time of sea-level highstand. The deposition of most of the interglacial units occurred over a period of 15 to 20 thousand years. Ages of the units are discussed in detail in the Methods and Results sections.

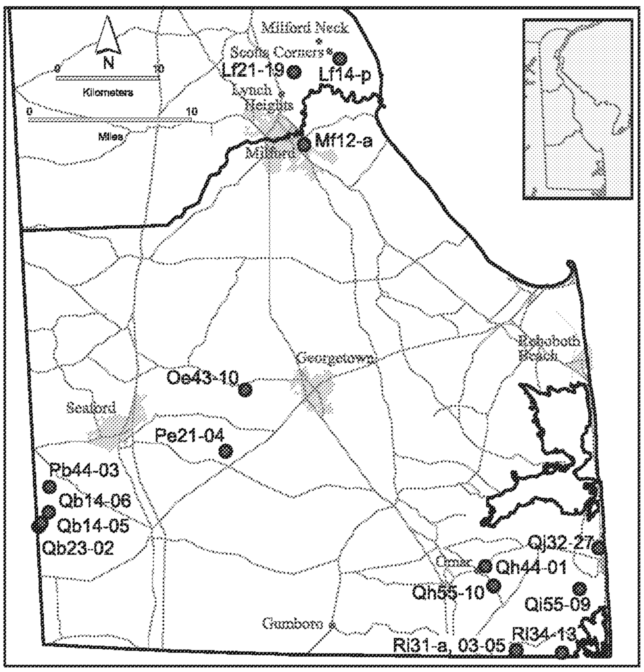

Figure 4. Location map for type and reference sections.

Delaware Bay Group

The Delaware Bay Group (Figs. 2, 5) consists of transgressive deposits that were laid down along the margins of ancestral Delaware Bay estuaries during middle to late Pleistocene rises and highstands of sea level.

Original reference: The Delaware Bay Group was described in detail by Ramsey (1997).

Type area: Ramsey (1997) defined the type area east and northeast of Milford, Delaware.

Type section: None designated. Refer to the type sections for the Lynch Heights and the Scotts Corners Formations.

Description: The Delaware Bay Group deposits consist of light reddish-brown to gray, medium to medium-to-coarse sands with common beds of fine to medium sand and very fine to fine sand and very fine to fine sandy silt. Also present are beds of gray clayey silt and brown, organic-rich clayey silt that are commonly found in lensoid channel-fill bodies. Beds of gray, fine to very fine clayey sand to clayey silt with shell are found in its eastern extent near Rehoboth Beach. The sands are quartzose with varying amounts of feldspar, slightly less than quantities of feldspar found in the Columbia Formation. The deposits are heterogeneous both vertically and laterally. The general trend within the formations is a fining upwards of sediment textures.

Geomorphology: The Delaware Bay Group deposits are found beneath terraces that have scarps roughly parallel to the Delaware River and Bay tributaries, and relatively flat treads that slope gently toward the modern Delaware Bay.

Depositional Environments: The Delaware Bay Group includes transgressive deposits consisting of stream, swamp, marsh, estuarine barrier and beach, tidal flat, lagoon, and shallow offshore estuary environments (Ramsey, 1997).

Age: The Delaware Bay Group is middle to late Pleistocene, 400,000 to 80,000 yrs B.P. (MIS 11 to MIS 5a).

Units: The Delaware Bay Group is comprised of the Lynch Heights Formation, the Scotts Corners Formation, and the Cape May Formation (undivided) in New Jersey. Ramsey (1997) suggested that the Pleistocene interglacial deposits on the New Jersey side of Delaware Bay be included in the Delaware Bay Group. The Cape May Formation has similar geomorphic characteristics, ages, and depositional environments (O'Neal and McGeary, 2002; Newell et al., 2001) to the Delaware Bay Group.

Lynch Heights Formation

The Lynch Heights Formation (Figs. 2, 5) is the oldest unit of the Delaware Bay Group. It is a composite formation of two separate high-stand deposits referred to as the older and younger Lynch Heights Formation (Ramsey, 1997).

Original reference: The Lynch Heights Formation was defined by Ramsey (1997).

Type area: The type area for the Lynch Heights Formation is north of Milford, Delaware, near the unincorporated village of Lynch Heights (Ramsey, 1997) (Fig. 5).

Areal extent: The Lynch Heights Formation extends along the margins of the Delaware estuary from Wilmington to Rehoboth Beach.

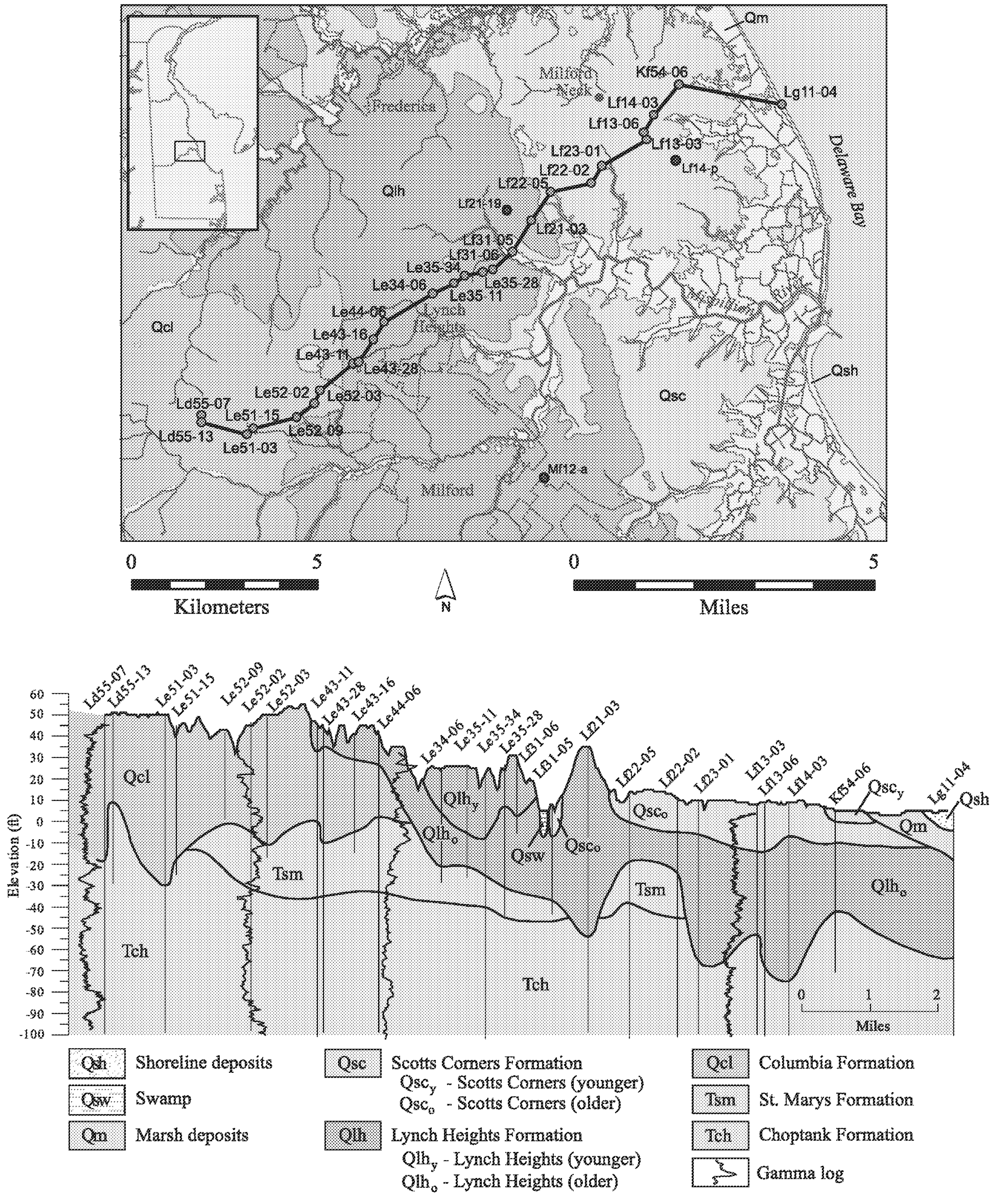

Figure 5. Cross section showing the stratigraphic relationships of the units of the Delaware Bay Group (Qsc, Qlh). Red circles in the top figure show locations of the Lynch Heights Formation type (Lf21-19) and reference (Mf12-a) sections and of the Scotts Corners type section (Lf14-p).

Table 2. Geographic coordinates and land surface elevations for the type sections (**bold**) and reference sections of the lithostratigraphic units mentioned in the text. Northings and eastings are in meters, UTM Zone 18. Elevations are in feet, NAVD 1988. Refer to Figure 4 for locations of data points.

DGS ID	Land Surface Elevation	Northing	Easting	Formation
Lf21-19	30	4313848.5	464370.5	Lynch Heights
Mf12-a	35	4306663.1	465374.7	Lynch Heights
Lf14-p	8	4315173.0	468892.3	Scotts Corners
Qh44-01	22	4264827.0	483348.6	Omar
Qh55-10	26	4262889.8	484164.0	Omar
Ri31-03	17	4256663.0	486630.1	Ironshire
Ri31-04	7	4256540.0	486411.5	Ironshire
Ri31-05	17	4256643.5	486534.3	Ironshire
Ri31-a	16	4256465.5	486403.7	Ironshire
Ri34-13	6	4256256.2	490947.8	Sinepuxent
Qi55-09	5	4262551.9	492709.3	Sinepuxent
Qj32-27	5	4266640.0	494586.4	Sinepuxent
Pb44-03	33	4272699.1	440097.3	Turtle Branch
Qb14-06	25	4270196.2	440034.9	Turtle Branch
Pe21-04	38	4276250.8	457581.1	Turtle Branch
Oe43-10	37	4282296.3	459533.0	Turtle Branch
Qb23-02	10	4268750.8	439014.8	Kent Island
Qb14-05	17	4269120.1	439293.9	Kent Island

Type section: The type section of the Lynch Formation is drill hole Lf21-19 (Ramsey, 1997) (Fig. 6). This locality as well as Mf12-a (indicated below as a reference section) show the typical sequence found within the Lynch Heights Formation where it is the surficial stratigraphic unit.

Reference section(s): The reference section for the Lynch Heights Formation is outcrop Mf12-a, which is a borrow pit just east of Milford (Ramsey, 1997) (Figs. 5, 7).

Description: The Lynch Heights Formation consists of light-yellowish and light-reddish-brown to gray, medium quartz sand with discontinuous beds of fine to very fine, silty sand, reddish-brown to brown clayey silt to silty clay, and organic-rich silt to silty sand. Beds of medium to coarse, pebbly sand and gravel with scattered cobbles and beds of coarse to granule sand are also common. Where the sands are fine- to very fine-grained, they are quartzose and slightly feldspathic and micaceous. Near the present Atlantic Coast between Lewes and Rehoboth Beach, the Lynch Heights Formation consists of gray, fine to very fine, clayey sand to silty clay with scattered shell laminae. The unit is up to 50 feet thick and thins away from the present Delaware Bay (Fig. 5).

Geomorphology: The Lynch Heights Formation is found beneath two terraces with scarps roughly parallel to the present Delaware estuary; one with its toe at approximately 45 feet and a tread that slopes to about 40 feet (older Lynch Heights Formation); another with a toe at approximately 30 feet and a

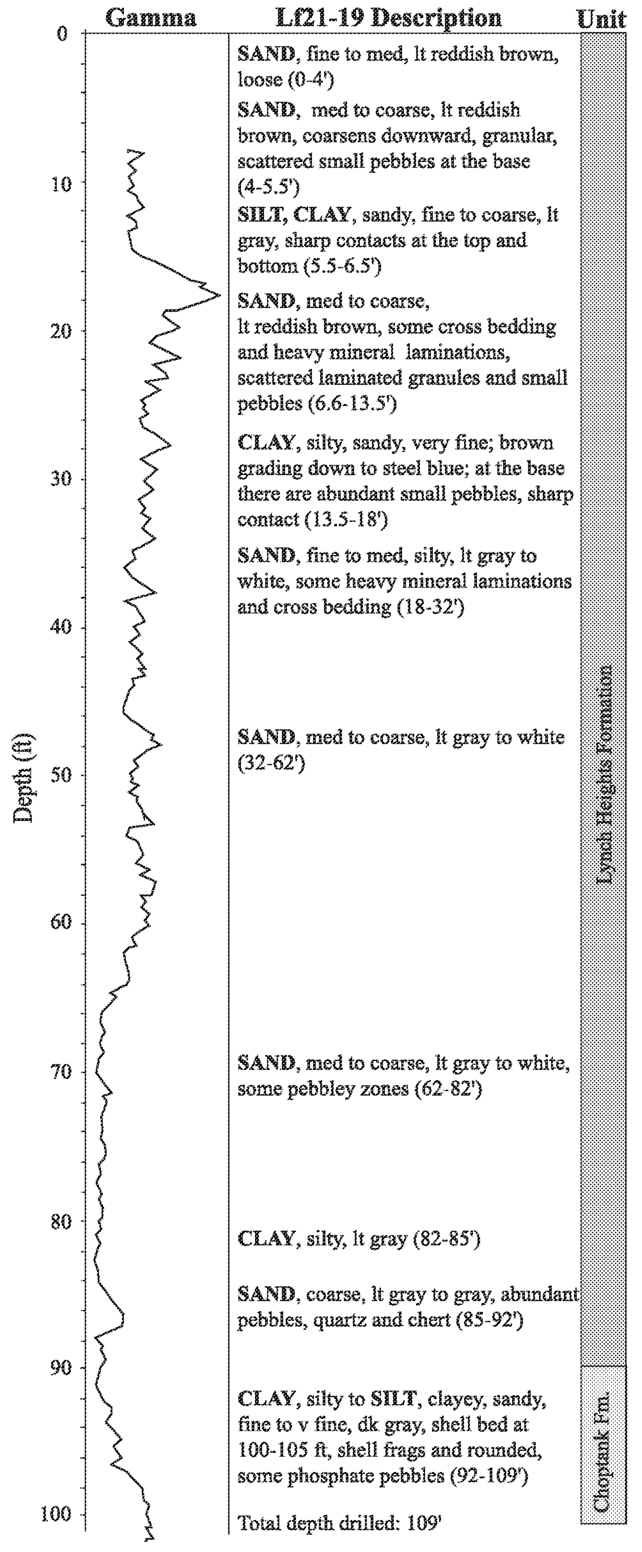

Figure 6. Type section (Lf21-19) for the Lynch Heights Formation. Geographic coordinates and land surface elevation are shown in Table 2. Modified from Ramsey, 1997. 0-32 ft from core, 32-90 ft from auger. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

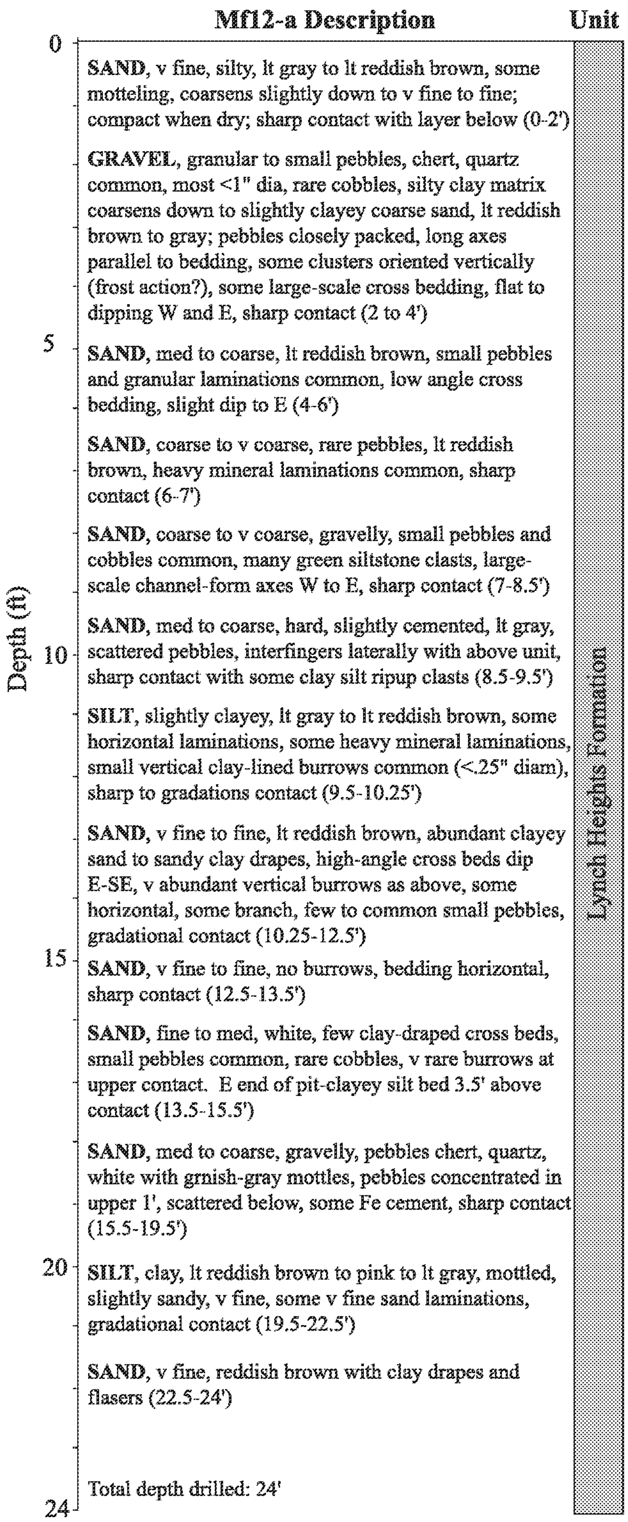

Figure 7. Reference section (Mf12-a) for the Lynch Heights Formation. Geographic coordinates and land surface elevation are shown in Table 2. Modified from Ramsey, 1997. Hand augered. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

tread that slopes to about 25 feet (younger Lynch Heights Formation).

Stream Networks: First and second order streams are common on the Lynch Heights Formation. The first order streams originate at the bounding scarp with older units inland. Third order streams are rare on the older Lynch Heights Formation surface (Ramsey 1997).

Depositional Environments: The transgressive deposits of the Lynch Heights Formation consist of stream, swamp, marsh, estuarine barrier and beach, tidal flat, lagoon, and shallow offshore estuary (Ramsey, 1997). The clayey sand to silty clay in the Rehoboth area was deposited in a lagoon that extended from the present town of Rehoboth to Lewes.

Stratigraphic Relationships: The Lynch Heights Formation unconformably overlies the Columbia Formation in southeastern Kent County and northeastern Sussex County, and the Beaverdam Formation in southeastern Sussex County. The formation typically has a bed of pebbly sand or gravel at its base.

Palynology/Climate: The pollen from the Lynch Heights Formation consists primarily of abundant *Pinus* with *Quercus*, and *Carya* commonly present. *Liquidambar* has not been identified and *Tsuga* is rare in the unit. The climate, based on pollen, ranged from cool temperate to warm temperate (Ramsey, 1997; Groot and Jordan, 1999). Refer to the palynology section for more details.

Aminozones: The younger Lynch Heights Formation contains shells with racemization ratios assigned to aminozone IIc.

Age: The Lynch Heights Formation is middle Pleistocene, approximately 400,000 yrs B.P. (older Lynch Heights Formation, MIS 11) and 330,000 yrs B.P. (younger Lynch Heights Formation, MIS 9) on the basis of stratigraphic position, correlation with the Omar Formation (older Lynch Heights Formation), and amino-acid racemization dating (younger Lynch Heights Formation).

Scotts Corners Formation

The Scotts Corners Formation (Figs. 2, 5) is the youngest unit of the Delaware Bay Group. It is a composite formation of two separate highstand deposits referred to as the older and younger Scotts Corners Formation (Ramsey, 1997).

Original reference: The Scotts Corners Formation was first defined by Ramsey (1993).

Type area: The Scotts Corners Formation was named after the cross-roads of Scotts Corners located on Milford Neck northeast of Milford near where the formation was first recognized from numerous shallow drill holes in the Milford Neck Wildlife Area (Ramsey, 1993).

Areal extent: The Scotts Corners Formation extends from north to south along the landward margin of the Delaware estuary from Wilmington to Lewes.

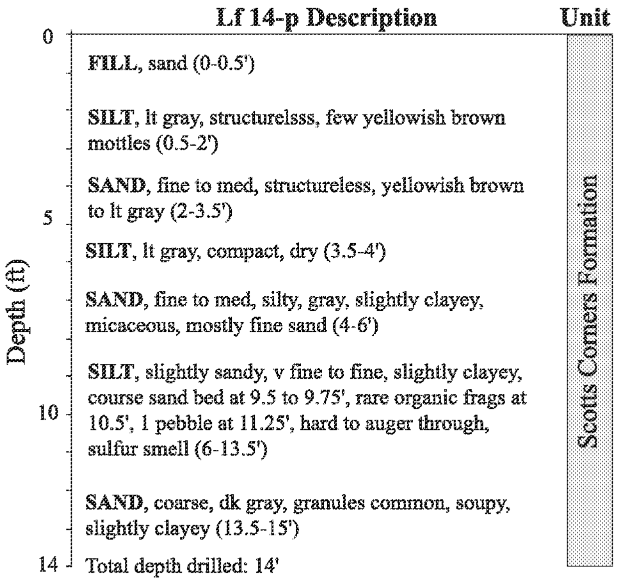

Figure 8. Type section (Lf14-p) for the Scotts Corners Formation. Geographic coordinates and land surface elevation are shown in Table 2. Modified from Ramsey, 1997. Soil auger boring. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

Type section: The type section of the Scotts Corners Formation is auger hole Lf14-p (Ramsey, 1993) (Fig. 8). The type section is not representative of the Scotts Corners Formation over its areal extent. It is typically sandier than the type section.

Reference section(s): None designated.

Description: The Scotts Corners Formation is a light-gray to brown to light-yellowish-brown, fine to coarse sand with discontinuous beds of organic-rich clayey silt, clayey silt, coarse to very coarse sand, and pebble gravel. The sands are quartzose with some feldspar and muscovite. Laminae of opaque heavy minerals are common.

Geomorphology: The older Scotts Corners Formation is found beneath terraces with scarps roughly parallel to the present Delaware Bay with toes at approximately 18 feet and a tread that slopes to about 10 feet. Another inset scarp with a toe at approximately 7 feet and a tread that slopes to about present sea level forms the surface of the younger Scotts Corners Formation. The unit is up to 20 feet thick and thins away from the present Delaware Bay (Fig. 5). South of Rehoboth Bay, the unit is less than 10 feet thick and has a patchy distribution (Fig. 2).

Stream Networks: First order streams are common on the younger Scotts Corners Formation and drain directly into the marsh bordering Delaware Bay. In addition to first order streams, second order streams are present on the older Scotts Corners Formation (Ramsey 1997).

Depositional Environments: The Scotts Corners Formation includes transgressive deposits consisting of stream, swamp, marsh, estuarine barrier and beach, tidal flat, and shallow offshore estuary environments (Ramsey, 1997).

Stratigraphic Relationships: The Scotts Corners Formation unconformably overlies the Lynch Heights Formation over much of its extent. It unconformably overlies older units where the Lynch Heights Formation is absent.

Palynology/Climate: The pollen from the Scotts Corners Formation consists primarily of abundant *Pinus* and *Quercus*. *Carya* is commonly present. In contrast to the Lynch Heights Formation, *Liquidambar* and *Tsuga* are both common in the Scotts Corners Formation. The climate was warm temperate (Ramsey, 1997; Groot and Jordan, 1999).

Aminozones: Shell material has not been found in the Scotts Corners Formation for amino-acid racemization.

Age: The Scotts Corners Formation is late Pleistocene, approximately 120,000 yrs B.P. (older, MIS 5e) and 80,000 yrs B.P. (younger, MIS 5a) on the basis of stratigraphic position (older Scotts Corners Formation) and correlation with the Sinepuxent Formation (younger Scotts Corners Formation).

Assawoman Bay Group (*herein named*)

The Assawoman Bay Group (Figs. 2, 9) consists of the well-sorted sands, silts, and clays of the previously defined Omar, Ironshire, and Sinepuxent Formations found adjacent to and inland of the Atlantic Coast of Delaware and Maryland. These deposits in Delaware and Maryland were named from oldest to youngest: the Omar Formation (Jordan, 1962, 1964), the Ironshire Formation (Owens and Denny, 1979a), and the Sinepuxent Formation (Owens and Denny, 1979a).

The Assawoman Bay Group consists of transgressive deposits that were deposited along the margins of an ancestral Atlantic Ocean during middle to late Pleistocene highstands of sea level. A cross section showing the relationships between the units of the Assawoman Bay Group is shown on Figure 9.

Original reference: Herein named.

Type area: The Assawoman Bay Group is named for the Little Assawoman Bay in Delaware and the Assawoman Bay in Maryland in the vicinity of where the Omar, Ironshire, and Sinepuxent Formations are best developed.

Areal extent: In Delaware, the Assawoman Bay Group extends south of Indian River Bay to east of Gumboro. In Maryland, it is mapped south and west of Salisbury (Owens and Denny, 1979a). It extends east of Salisbury into the Virginia portion of the Delmarva Peninsula (Mixon, 1985).

Type section: None designated. Refer to the type section and reference sections of the Omar Formation, Ironshire and Sinepuxent Formations.

Description: The Assawoman Bay Group consists of heterogeneous units of fine to coarse, quartzose sand interbedded and interlaminated with clayey silt, sandy silt, and silty clay overlain by fine to coarse sand at the land surface. The finer-grained beds commonly have organic-rich horizons of plant

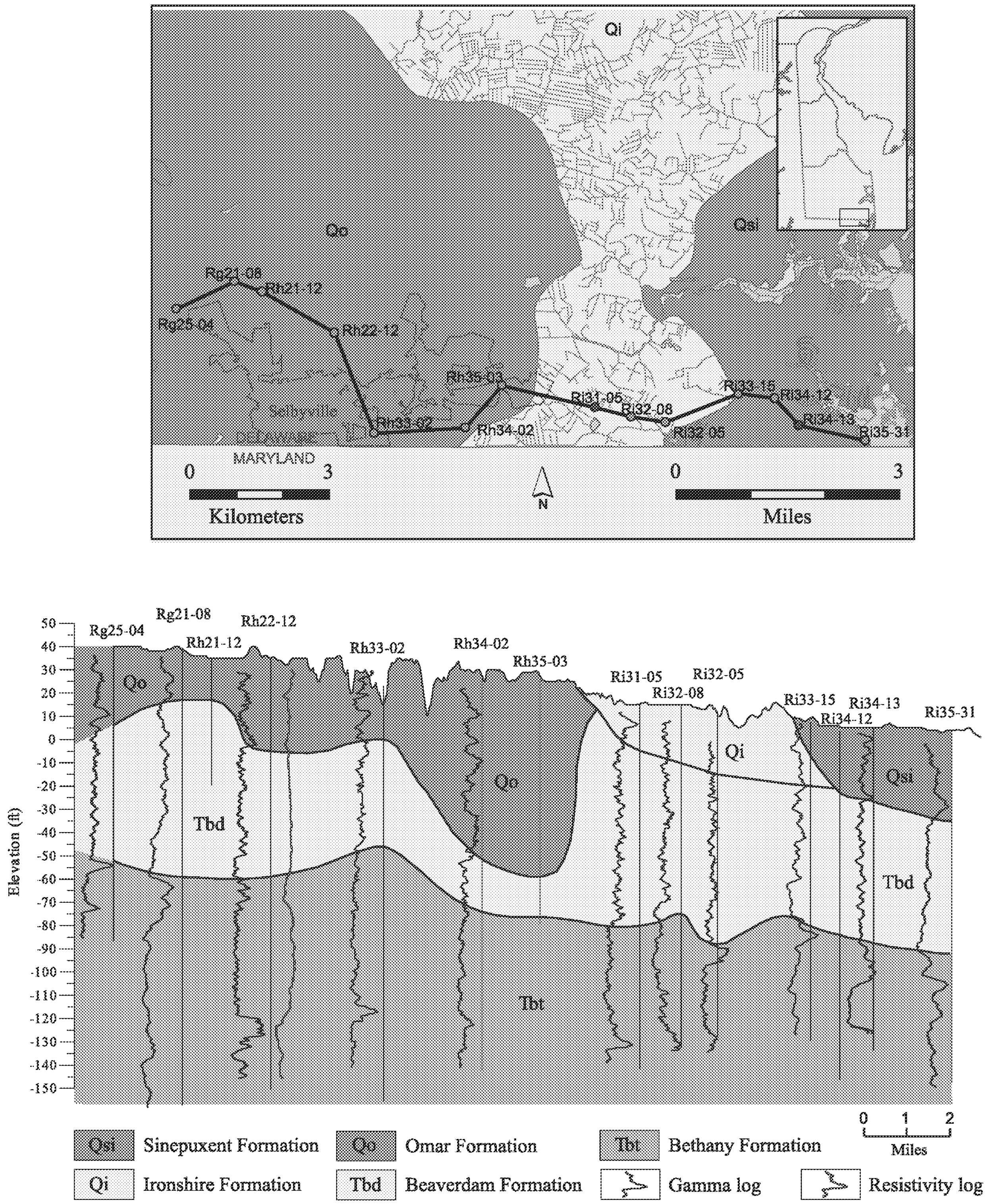

Figure 9. Cross section showing the stratigraphic relationships of the units of the Assawoman Bay Group (Qsi, Qi, Qo). Red circles in the top figure show locations of the reference sections for the Ironshire Formation (Ri31-05) and the Sinepuxent Formation (Ri34-13).

material, ranging from peat to leaves and twigs to stumps, and less commonly, shell beds of moderate- to low-salinity-tolerant mollusks.

Geomorphology: The Assawoman Bay Group is found beneath terraces with scarps roughly parallel to the modern Atlantic Coast. Laterally, the Assawoman Bay Group is contiguous with the Delaware Bay Group.

Depositional Environments: The Assawoman Bay Group is a transgressive deposit consisting of nearshore, barrier, lagoon, marsh, swamp, and fluvial depositional environments (Owens and Denny, 1979a; Mixon, 1985).

Stratigraphic Relationships: The Assawoman Bay Group unconformably overlies the Beaverdam Formation.

Age: The Assawoman Bay Group is middle to late Pleistocene, 400,000 to 80,000 yrs B.P. (MIS 11 to MIS 5a).

Units: The Assawoman Bay Group consists of the Omar Formation, the Ironshire Formation, and the Sinepuxent Formation.

Omar Formation

The Omar Formation (Figs. 2, 9) is the oldest unit of the Assawoman Bay Group. It consists of swamp to nearshore deposits that fill and overtop a paleovalley south of the present Indian River (Owens and Denny, 1979a).

Original reference: The Omar Formation was originally defined by Jordan (1962).

Type area: The type area for the Omar Formation is near the crossroads of Omar, Delaware (Jordan, 1962).

Areal extent: In Delaware, the Omar Formation extends south of Indian River and its tributaries into Maryland and east of the western margin of Cypress Swamp. It continues south into Maryland (Owens and Denny, 1979a) and Virginia (Mixon, 1985).

Type section: The type section of the Omar Formation was defined by Jordan (1962) as well Qh44-01 (Fig. 10).

Reference section(s): The reference section for the Omar Formation is designated herein as drill hole Qh55-10 (Fig. 11).

Description: The Omar Formation was originally described (Jordan, 1962) as consisting of interbedded, gray to dark gray, quartz sands and silts with bedding ranging from a few inches to more than 10 feet thick. Thin laminae of clay are found within the fine, well-sorted sands. Silt mixed with sand generally contains some plant matter and where dark in color could be considered organic. Sands contain wood fragments, some of which are lignitic.

On the basis of regional mapping by the author, the description of the Omar Formation is modified from that of Jordan (1962). The Omar Formation consists of quartzose, greenish-gray to light-yellow, homogeneous, fine to very fine sand with scattered medium to coarse laminae commonly overlain by dark-greenish-gray, silty clay to clayey silt with scattered shell beds and bioherms of the oyster *Crassostrea*. The silty clay is overlain by a light-gray, fine to coarse sand. Coarse sand and gravel interspersed with organic-rich horizons that include stumps and logs of cypress trees (e.g., 40-45 ft depth, Qh55-10, Fig. 11) is found both at the base of the Omar Formation and at the top of the silty clay. The Omar Formation ranges from 10 to 80 feet thick. In the western portions of its extent in the vicinity of Cypress Swamp and to the north where it grades into the Lynch Heights Formation, the unit is typically a sheet of moderately well sorted to well sorted, fine to coarse sand.

Geomorphology: The Omar Formation is found beneath a terrace bounded to the west by a scarp with a toe at approximately 42 feet with a tread that slopes to about 25 feet. The Omar Formation fills and overtops a roughly east-west trending paleovalley extending from offshore of the present Delaware Coast into Maryland east of Selbyville, Delaware (Owens and Denny, 1979a). The unit is thickest where it fills the deepest portions of this paleovalley (Fig. 9).

Stream Networks: First, second, and third order streams drain the surface of the Omar Formation. First order streams originate at the bounding scarp with the Beaverdam Formation.

Depositional Environments: The Omar Formation is primarily lagoonal (homogeneous sands and silty clays with oysters), tidal stream (organic rich silts and clays and sands with stumps and organic fragments), and nearshore sand (well-sorted sands). Pollen from clays within the unit indicates a period of fresh water (bog), cold climate deposition overlain and underlain by warmer climate deposits (Groot et al., 1990).

Stratigraphic Relationships: The Omar Formation unconformably overlies the Beaverdam Formation. The contact is recognized by the contrast in the gray clayey silt or relatively cleaner sands and gravelly sands of the Omar Formation over the siltier sands of the Beaverdam Formation.

Palynology/Climate: The pollen from the Omar Formation consists primarily of abundant *Pinus* and common to abundant *Quercus* and *Carya*. *Liquidambar* and *Tsuga* are both common in the unit. The climate ranged from cool temperate to warm temperate (Ramsey, 1997; Groot and Jordan, 1999). A few cool- to cold-climate pollen samples are stratigraphically bracketed above and below by temperate climate pollen samples (Qh44-01, Groot and Jordan, 1999).

Aminozones: Racemization data from shells located within the Omar Formation are assigned to aminozones IId and IIc.

Age: The Omar Formation is middle Pleistocene, approximately 400,000 (MIS 11) and 325,000 (MIS 9) yrs B.P. on the basis of amino-acid racemization dating. Groot et al. (1990) and Groot and Jordan (1999) indicated that the lowermost Omar Formation may be Pliocene in age based on exotic pollen forms found within a few samples that they interpreted as occurring near the base of the Omar Formation. There is no other evidence to indicate that a portion of the unit is as old as Pliocene.

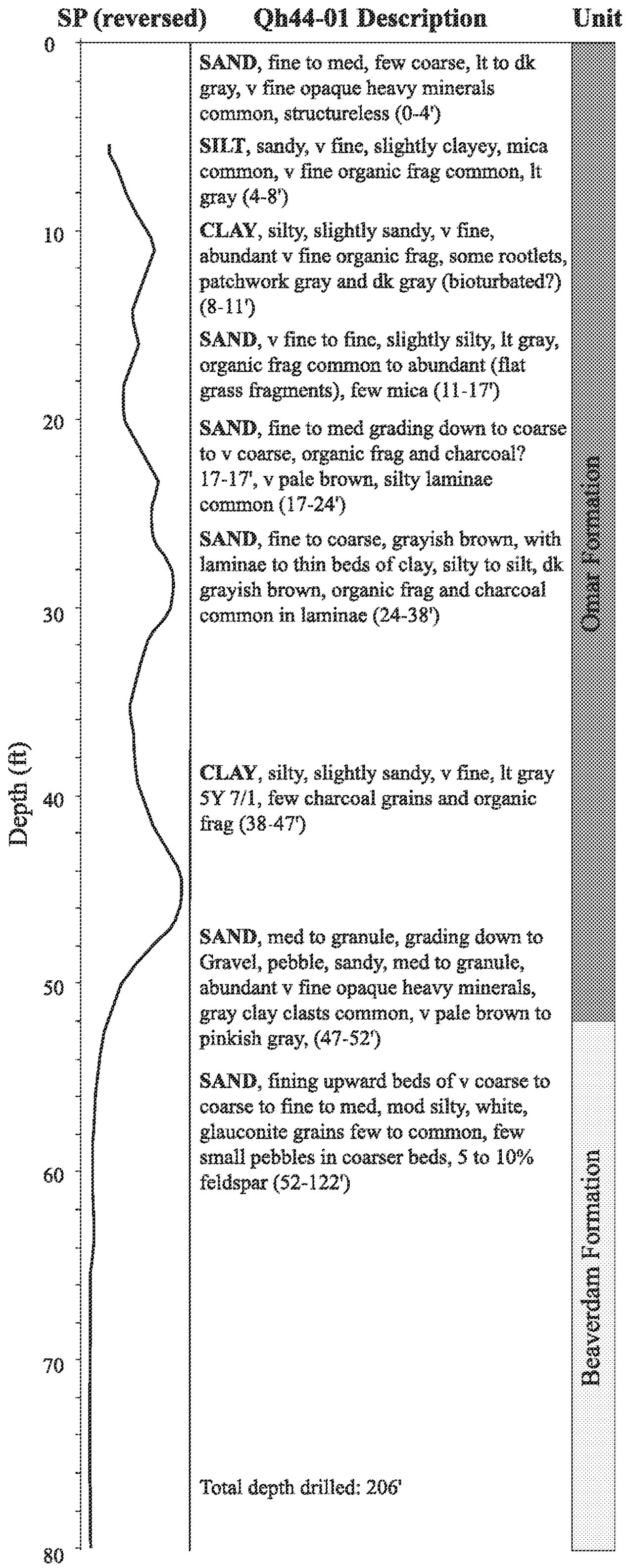

Figure 10. Type section (Qh44-01) for the Omar Formation. Geographic coordinates and land surface elevation are shown in Table 2. Description based on split spoon samples. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

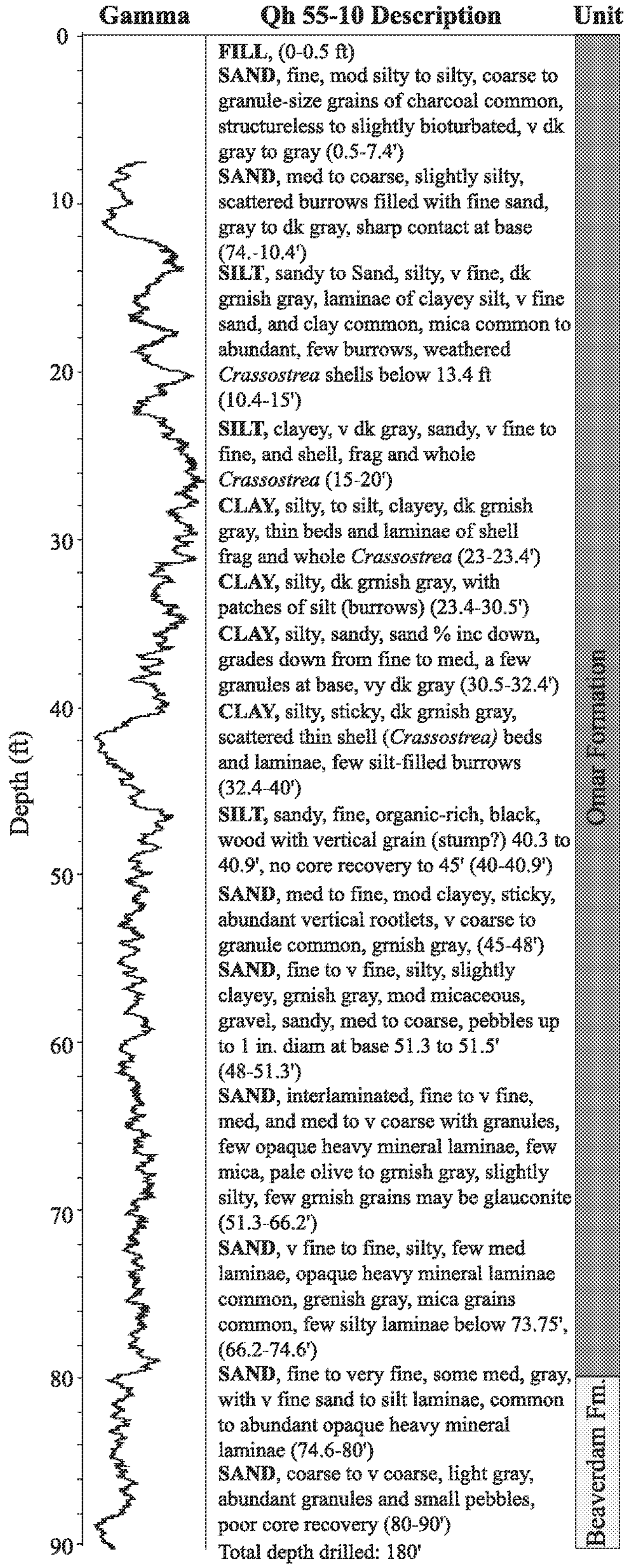

Figure 11. Reference section (Qh55-10) for the Omar Formation. Geographic coordinates and land surface elevation are shown in Table 2. Descriptions made from wireline core. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

Ironshire Formation

The Ironshire Formation (Figs. 2, 9) forms the medial unit of the Assawoman Bay Group. It consists of beach, nearshore, and sandy lagoonal deposits.

Original references: The Ironshire Formation was originally definded by Owens and Denny (1978, 1979a).

Type area: Owens and Denny (1978, 1979a) defined the type area for the Ironshire Formation as the borrow pits located near Ironshire, Maryland.

Areal extent: In Delaware, the Ironshire Formation extends in a belt south of Indian River from Millsboro southeast to Millville, and southwest to the Maryland state line. In Maryland, it extends in a restricted strip parallel to the present Atlantic Coast almost to the Maryland-Virginia border (Owens and Denny, 1978, 1979a).

Type section: None designated.

Reference section(s): The reference section for the Ironshire Formation is a composite log of Ri31-03, Ri31-04, Ri31-05, and Ri31-a (Fig. 12).

Description: The Ironshire Formation was described by Owens and Denny (1979a) as consisting of a lower loose, pale-yellow to white, well-sorted, medium sand characterized by long, low-angle inclined beds with laminae of black minerals. The upper portion of the units was described as consisting of light-colored, trough cross-stratified, well-sorted sand with pebbles and a few *Callianassa* borings. They described the Ironshire Formation near Rehoboth in a stratigraphic section which is now considered to be a part of the Lynch Heights Formation.

Detailed mapping is needed to clearly describe the unit in Delaware. Based on limited investigation in Delaware by the author, the Ironshire Formation is a fine to medium, sugary sand overlying a gray, silty clay that is flaser- to wavy-bedded with fine to medium sand overlying gray, silty clay with scattered organic-rich laminae in its reference area. To the north toward Indian River Bay, the Ironshire Formation is a fine to medium sand with coarse laminae and scattered pebbles and rare, scattered shelly zones and silty clay beds. The sands are quartzose with less than 10 percent feldspar. The Ironshire Formation is rarely over 20 feet thick (Fig. 9).

Geomorphology: The Ironshire Formation is found beneath a terrace bounded to the west by a scarp with a toe at approximately 20 feet with a tread that slopes to about 15 feet. The Ironshire Formation in Delaware is contiguous to the Ironshire Formation as mapped in Maryland (Owens and Denny, 1978).

Stream Networks: First and second order streams drain the surface of the Ironshire Formation. The first order streams originate at the scarp with the Omar Formation.

Depositional Environments: The Ironshire Formation consists of transgressive deposits laid down in sandy lagoon and nearshore depositional environments based on the presence of *Callianassa* burrows (Owens and Denny, 1979a). Owens and Denny (1979a) also considered a portion of the unit to be fluviatile to estuarine. These environments have not been documented in Delaware.

Stratigraphic Relationships: The Ironshire Formation unconformably overlies the Omar Formation or the Beaverdam Formation where the Omar Formation is absent. The contact is easily recognized where the sands of the Ironshire Formation overlie the Beaverdam Formation by the contrast of the better sorted, cleaner sands of the Ironshire Formation over the silty sands of the Beaverdam Formation. The contact may also be readily recognized where gray, organic-rich clays or clayey sands of the Ironshire Formation overlie the coarse sands of the Beaverdam Formation. Where the Ironshire Formation overlies the Omar Formation, the boundary is not always clear but is commonly marked by a coarse sand or pebbly sand at the base of the Ironshire Formation.

Palynology/Climate: Limited pollen data available from the Ironshire Formation indicate flora dominated by *Pinus* and *Quercus* and a climate of temperate to cool temperate.

Aminozones: Shell material has not been found in the Ironshire Formation for amino-acid racemization.

Age: The Ironshire Formation is late Pleistocene, approximately 120,000 yrs B.P. (MIS stage 5e) on the basis of stratigraphic position.

Sinepuxent Formation

The Sinepuxent Formation (Figs. 2, 9) is the youngest unit of the Assawoman Bay Group.

Original reference: Owens and Denny (1979a) first described in the Sinepuxent Formation.

Type area: The type area for the Sinepuxent Formation is Sinepuxent Neck between Berlin and Ocean City, Maryland (Owens and Denny, 1979a).

Areal extent: In Delaware, the Sinepuxent Formation extends south of Indian River in a belt roughly parallel to the Atlantic Coast from just west of Indian River Inlet south into adjacent Maryland. It continues in a narrow strip along the Maryland Coast to just north of the Maryland-Virginia border (Owens and Denny, 1979a).

Type section: None designated.

Reference section(s): The reference sections for the Sinepuxent Formation include Ri34-13 (Fig. 13), Qi55-09 (Fig. 14), Qj32-27 (McLaughlin et al., 2008), which is generalized in Figure 15.

Description: Owens and Denny (1979a) described the Sinepuxent Formation in Maryland as dark, poorly sorted, silty fine to medium sand with the lower part of the unit being fine grained with thin beds of black clay. The Sinepuxent Formation is described as being lithically distinct from the Omar and Ironshire Formations due to the presence

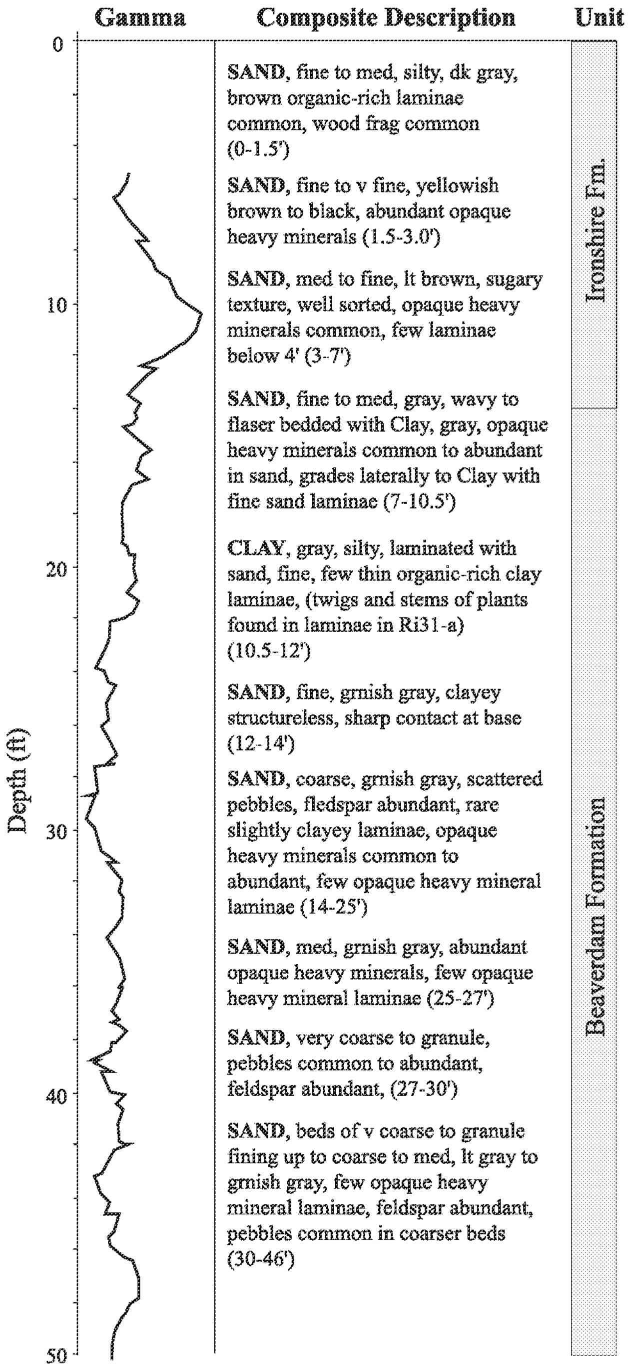

Figure 12. Reference section for the Ironshire Formation. This is a composite descriptive log of Ri31-03, Ri31-04, and Ri31-a. Ri31-03,-04, and -05 were drilled within 900 ft of each other. Ri31-03 and -04 were split-spoon cored to a depth of 36' and 46', respectively. Ri31-05 was augered to a depth of 160' and a gamma log was collected through the augers. Outcrop Ri31-a was described from a borrow pit nearby Ri31-03. Geographic coordinates and land surface elevation are shown in Table 2. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

and abundance of micaceous minerals. The upper part of the unit was described as being light-colored, well-sorted sand that overlies brown peat to peaty sand.

In Delaware, the Sinepuxent Formation is the most distinctive unit of the Assawoman Bay Group, consisting of gray, laminated, silty very fine to fine, quartzose, micaceous, sand to sandy silt. The base of the unit is typically a bluish-gray to dark-gray clayey silt to silty clay. There are a few shelly zones within the Sinepuxent Formation in the vicinity of Bethany Beach (McDonald, 1981; McLaughlin et al., 2008). The Sinepuxent Formation is up to 40 feet thick (Fig. 9).

Geomorphology: The Sinepuxent Formation is found beneath a terrace bounded to the west by a scarp with a toe at approximately 12 feet in elevation with a tread that slopes to present sea level.

Stream Networks: The Sinepuxent Formation is drained primarily by first order streams that originate at the scarp with the Ironshire Formation and end in marsh or are drowned by the upper reaches of Little Assawoman or Assawoman Bays.

Depositional Environments: The Sinepuxent Formation was deposited in quiet-water lagoon and nearshore depositional environments (Owens and Denny, 1979a; McLaughlin et al., 2008).

Stratigraphic Relationships: The Sinepuxent Formation unconformably overlies the Omar Formation or the Beaverdam Formation where the Omar Formation is absent (Fig. 9). It unconformably overlies the Ironshire Formation near the western margin of the Sinepuxent Formation. The micaceous sands of the Sinepuxent Formation readily contrast the unit from the underlying Ironshire, Omar, or Beaverdam Formations.

Palynology/Climate: The pollen assemblage from the Sinepuxent Formation is distinctive with abundant *Pinus*, uncommon *Quercus*, and common *Picea* indicating a cool climate (McLaughlin et al., 2008).

Aminozones: Racemization data from shells located within the Sinepuxent Formation are assigned to aminozone IIa.

Age: The Sinepuxent Formation is late Pleistocene, approximately 80,000 yrs B.P. (MIS 5a) on the basis of amino-acid racemization dating. Owens and Denny (1979a) reported a radiocarbon date of 31,000 yrs B.P. from peat near the top of the unit, and a date of 28,750 yrs B.P. from shell material within the unit.

Nanticoke River Group (*herein named*)

The Nanticoke River Group (Figs. 2, 16) consists of the fine to coarse sand and clayey silts to silty clays of the Turtle Branch and Kent Island Formations. The informal term "Nanticoke deposits" was used by Andres and Ramsey (1995, 1996) for Quaternary sediments along the Nanticoke River in the vicinity of Seaford in western Sussex County. These deposits included estuarine sediments as well as eolian dunes along the margins of the Nanticoke River. More recent mapping in the Georgetown area in 2006 and 2007 (Ramsey, 2010), as well as along the Nanticoke River to the southwest of Seaford in 2005 (unpublished DGS data), has allowed for more detailed analysis of the deposits and for recognition of two stratigraphic units within what was mapped as the Nanticoke deposits.

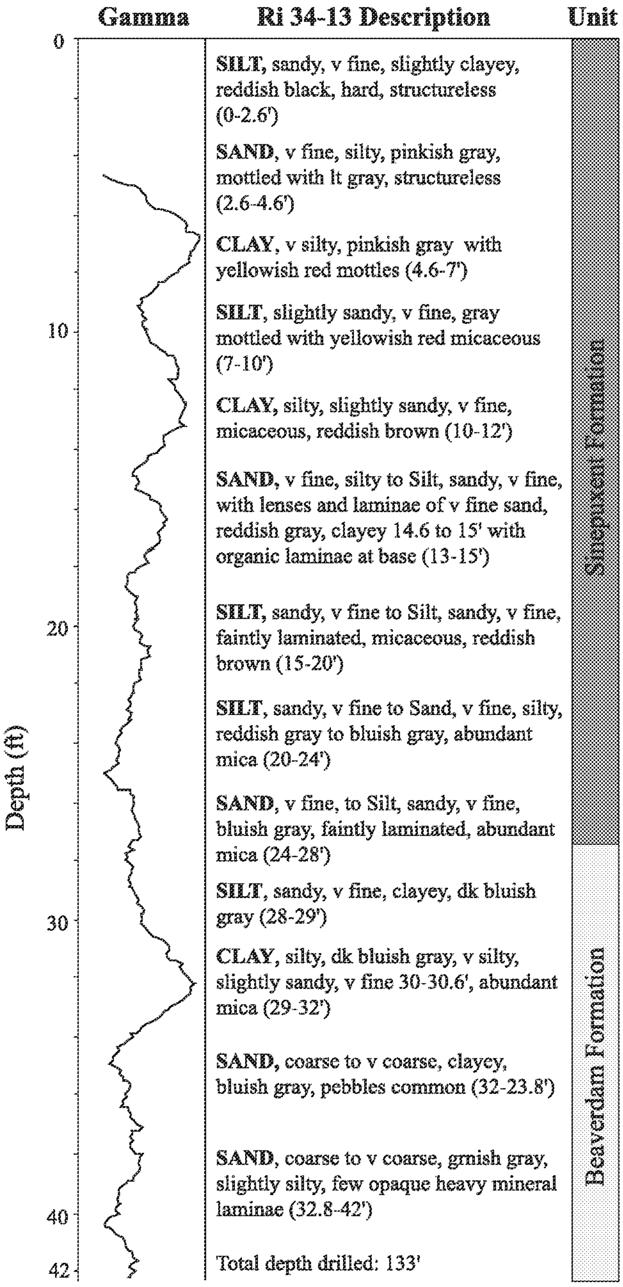

Figure 13. Reference section (Ri34-13) for the Sinepuxent Formation. Geographic coordinates and land surface elevation are shown in Table 2. Core described using split-spoon samples. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

It is proposed that the term Nanticoke deposits be replaced by two stratigraphic units: the Kent Island Formation (Owens and Denny, 1979a), previously mapped in adjacent Maryland, and a new unit, the Turtle Branch Formation. It is also proposed that these two units be considered together as the Nanticoke River Group. Eolian (dune) sediments previously included in the Nanticoke deposits (Andres and Ramsey, 1995) are now mapped separately and not included in the Nanticoke River Group.

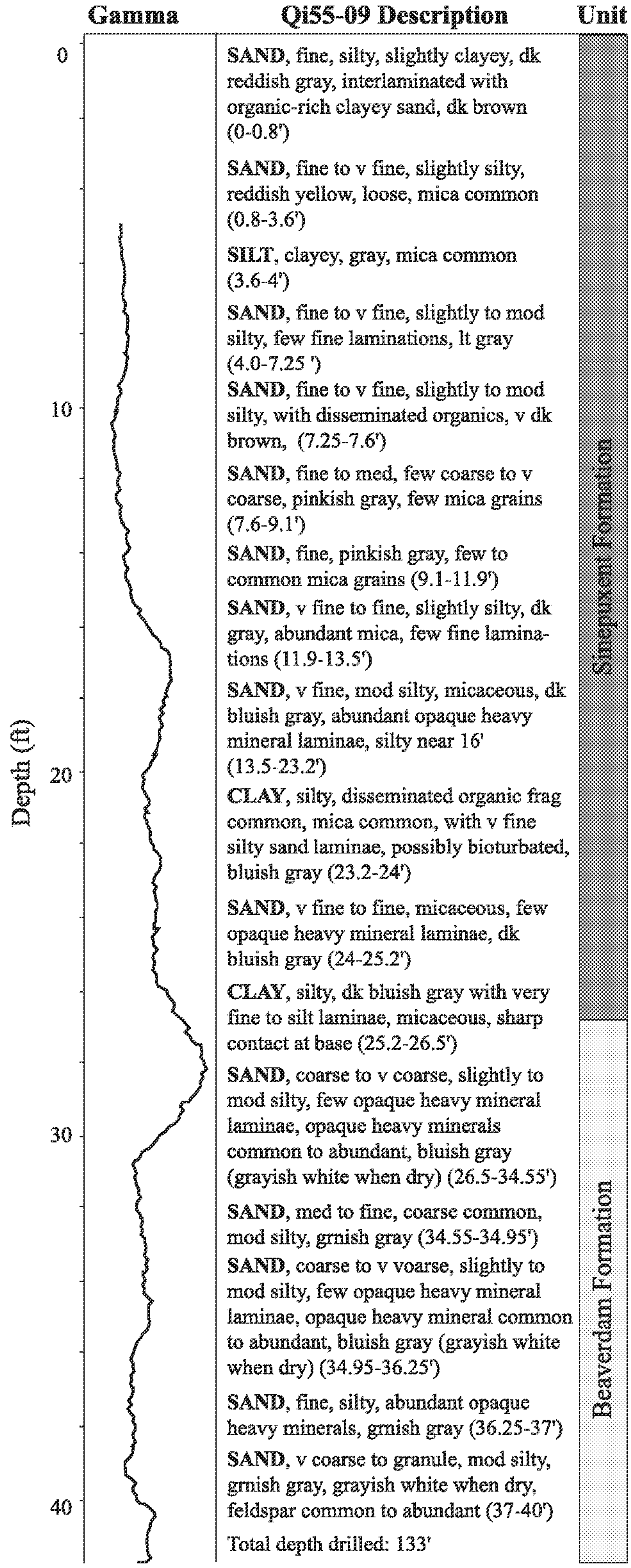

Figure 14. Reference section (Qi55-09) for the Sinepuxent Formation. Geographic coordinates and land surface elevation are shown in Table 2. Core described using split-spoon samples. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

The Nanticoke River Group consists of fluvial to estuarine, fine to coarse sand and estuarine clayey silts to silty clays that were deposited during highstands of sea level during the late Pleistocene. In Delaware, these deposits

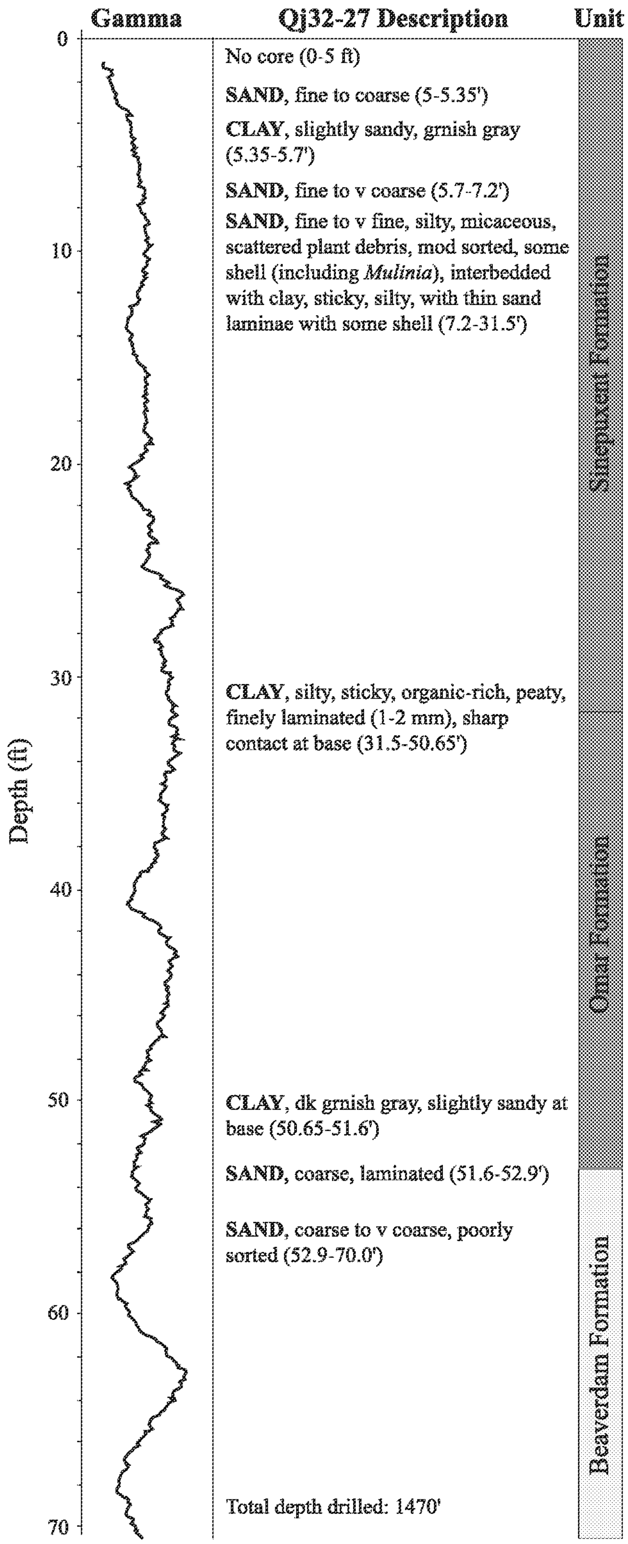

Figure 15. Reference section (Qj32-27) for the Sinepuxent Formation. Geographic coordinates and land surface elevation are shown in Table 2. Descriptions and stratigraphic picks for Omar and Beaverdam Formations are from Miller et al. (2003) and McLaughlin et al. (2008). Numbers in parentheses denote an interval of feet below land surface in which this unit described was found.

underlie terraces that flank the margins of the present Nanticoke River and its tributaries. Upstream the terraces become less distinct, and in places the surface of the Nanticoke River Group does not have a distinctive boundary scarp with the adjacent Beaverdam Formation. The Nanticoke River Group sands, however, are distinct and readily discernable from those of the Beaverdam Formation; the Nanticoke River Group sands are more well sorted, less feldspathic, and lack the distinctive white silty matrix of the Beaverdam Formation. Cross-sectional relationships between the units of the Nanticoke River Group are shown in Figure 16.

Original reference: Herein named.

Type area: In Delaware, the type area for the Nanticoke River Group is along the Nanticoke River and its tributaries.

Areal extent: In Delaware, the Nanticoke River Group extends along the margins of the Nanticoke River and its tributaries. It continues along the Nanticoke River into adjacent Maryland.

Type section: None designated. Refer to the type section and reference sections of the Turtle Branch Formation and the Kent Island Formation.

Description: The Nanticoke River Group consists of heterogeneous units of interbedded fine to coarse sand, clayey silt, sandy silt, and silty clay. Where the units are muddy, downstream of Seaford, the sequence consists of a lower fluvial to estuarine swamp to tidal stream deposits (coarse sand to gravelly sand with scattered organic-rich muddy beds) overlain by estuarine clayey silts and silty clays that contain rare to common *Crassostrea* (oyster) bioherms. The silts and clays are overlain by sands with clay laminae, to fine to coarse well-sorted, clean sand that are estuarne beach and eolian in origin. Upstream, the mud beds are rarer and restricted to the west side of streams and consist of organic-rich clayey silt. Most of the stratigraphic section is dominated by clean, well-sorted sands.

Geomorphology: The Nanticoke River Group is found beneath terraces with scarps roughly parallel to the modern Nanticoke River.

Depositional Environments: The Nanticoke River Group is comprised of deposits related to a rise and highstand of sea level and consist of beach (well-sorted, cross-bedded sand), tidal flat (well-sorted sand with clay laminae), open estuary (clayey silt with oyster shells), marsh (organic silts with grass plant fragments), swamp (organic silt to organic sand with woody fragments), and fluvial (poorly sorted sand and gravelly sand) depositional environments.

Stratigraphic Relationships: The Nanticoke River Group unconformably overlies the Beaverdam Formation. In the valley of the Nanticoke River it may, in places, unconformably overlie the Cat Hill Formation (Andres, 2004). The relationships between the Turtle Branch and Kent Island Formations, and the underlying Beaverdam Formation are shown in Figure 16.

Age: The Nanticoke River Group is middle to late Pleistocene, 400,000 to 80,000 yrs B.P. (MIS 11 to MIS 5a).

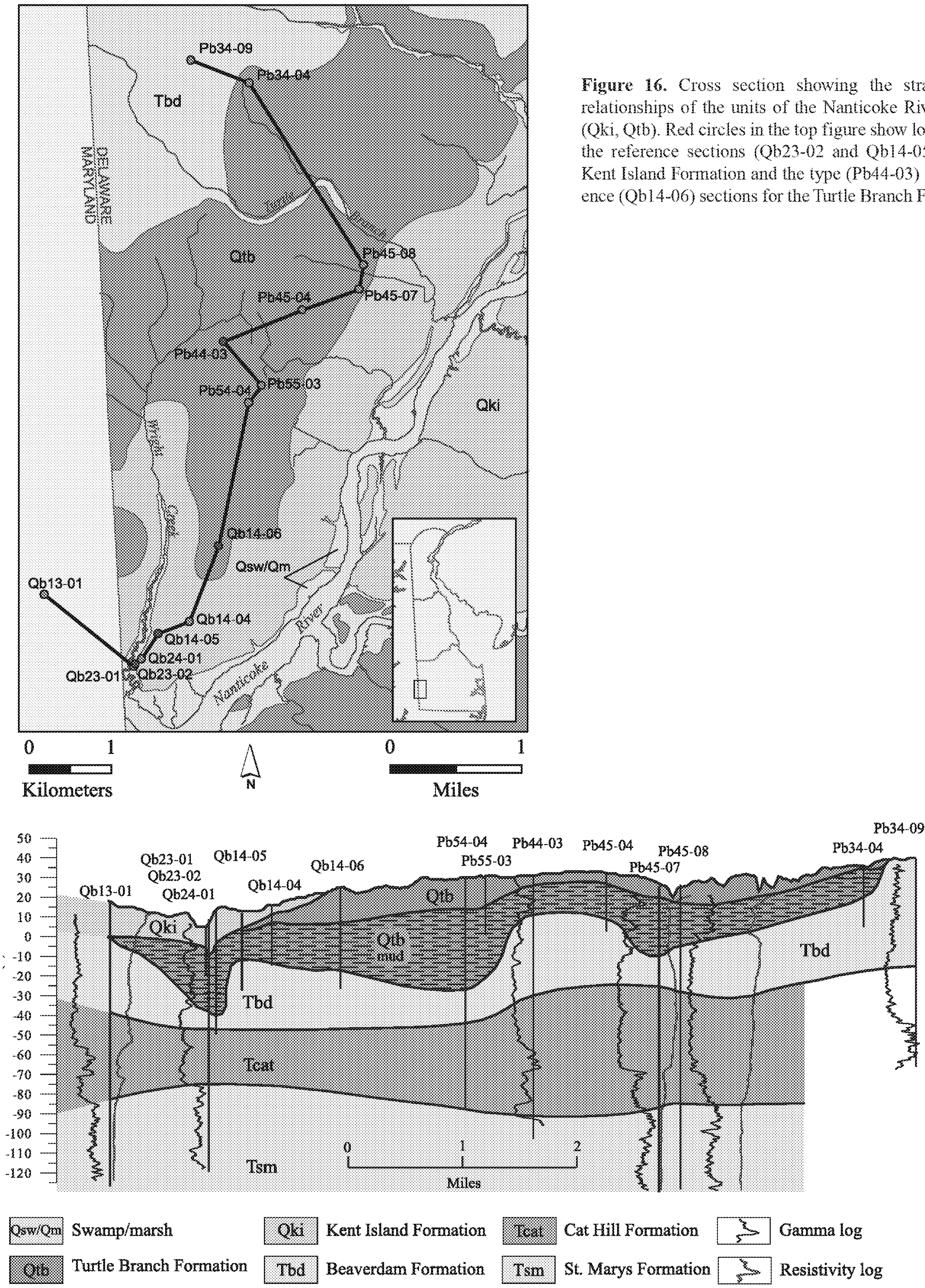

Figure 16. Cross section showing the stratigraphic relationships of the units of the Nanticoke River Group (Qki, Qtb). Red circles in the top figure show locations of the reference sections (Qb23-02 and Qb14-05) for the Kent Island Formation and the type (Pb44-03) and reference (Qb14-06) sections for the Turtle Branch Formation.

Units: The Nanticoke River Group is comprised of the Turtle Branch Formation (this report) and the Kent Island Formation (Owens and Denny, 1979a).

Turtle Branch Formation (*herein named*)

The Turtle Branch Formation (Figs. 2, 16) is the oldest and geomorphically highest unit of the Nanticoke River Group. It represents deposition during sea-level rise and highstand along the tributaries and margins of an ancestral Chesapeake Bay during the middle Pleistocene. Like the Omar Formation, it likely contains deposits from two separate highstands of sea level that are lithologically similar and are mapped together. Scattered pollen samples from within the Turtle Branch Formation are indicative of cool or cold climate (Andres and Ramsey, 1996) and may be related to a period of exposure between two warmer periods of deposition.

Original reference: Herein named.

Type area: The type area for the Turtle Branch Formation is near the west side of the Nanticoke River southwest of Seaford, Delaware (Fig. 16).

Areal Extent: In Delaware, the Turtle Branch Formation extends along the margins of the Nanticoke River and its tributaries. It continues into adjacent Maryland (Owens and Denny, 1979b).

Type section: The type section of the Turtle Branch Formation is drill hole Pb44-03 (Figs. 16, 17).

Reference section(s): Reference sections for the Turtle Branch Formation include Qb14-06, Pe21-04, and Oe43-10 (Figs. 18, 19, and 20, respectively).

Description: The Turtle Branch Formation in its type area consists of a 2- to 5-foot-thick, basal, olive-brown, coarse to very coarse sand with pebbles and scattered organic-rich, silty laminae. The basal sand is overlain by a 10- to 25-foot-thick, compact, greenish-gray to gray, silty clay with a few sand-filled burrows and scattered beds of *Crassostrea* that have increasing amounts of silt and sand laminae up section. The unit is capped by a 1- to 8-foot-thick, medium to coarse, well-sorted sand that in places contain thin organic-rich silty clays.

North of the type area the base of the unit is characterized by clean, very coarse to gravelly sand with rare organic-rich silty to clayey sand beds. The clays become increasingly sandy and thin, and are absent where Gravelly Branch intersects the Nanticoke River.

Along the tributaries to the Nanticoke River that trend toward the center of the Delmarva Peninsula, the Turtle Branch Formation is a loose, pale-yellow, well-sorted medium to coarse sand with scattered opaque heavy mineral, coarse sand to granule, and thin silty clay laminations. On the western side of some of the streams, more than 10 feet of organic-rich silty to clayey sand has been observed in the Turtle Branch Formation.

Previous work in the vicinity of the Nanticoke River (Jordan, 1964; Andres et al., 1995) documented the mineralogy of the sediments that are now assigned to the Turtle Branch Formation. The sands are quartzose with up to 20 percent feldspar (Jordan, 1964; Andres et al., 1995). The gravel fraction is dominated by quartz and quartzite with up to 30 percent chert (Andres et al., 1995). The clay fraction ranges from mostly kaolinite to a mix of illite, kaolinite, and smectite (Andres et al., 1995). I generalized the sand and clay mineralogy using the data that could definitely be related to either the Turtle Branch or Kent Island Formations. Most of the data reported by Andres et al. (1995) is from the Turtle Branch Formation, with some addition of samples from late Pleistocene to Holocene dunes along the Nanticoke River and a few from the Kent Island Formation.

The thickness of the Turtle Branch Formation ranges from 25 to 45 feet south of Seaford to 3 to 15 feet along tributaries of the Nanticoke River west of Georgetown (Fig. 16).

Geomorphology: In its type area, the Turtle Branch Formation is found beneath a terrace bounded to the west by a scarp with a toe at approximately 37 feet with a tread that slopes east to approximately 25 feet. The terrace scarp becomes less distinct up the tributaries of the Nanticoke River and the terrace surface rises to about 45 feet in the Georgetown Quadrangle (Ramsey, 2010). In the Georgetown Quadrangle along Deep Creek and Gravelly Branch, the surficial contact between the Turtle Branch Formation and the Beaverdam Formation lies beneath a flat landscape without any discernable or at best a very subtle topographic break.

Stream Networks: First, second, and third order streams drain the surface of the Turtle Branch Formation. First order streams are found at or near the contact with the Beaverdam Formation. A few fourth order streams are present.

Depositional Environments: In the type area, the base of the Turtle Branch Formation is interpreted to have been deposited in fluvial to swamp environments. Poorly sorted pebbly and gravelly sands with organic fine laminae represent deposition in streams and swampy areas as sea level rose. These sands are overlain by the muddy sands and clays with oyster shells that were deposited when the ancestral Nanticoke River was estuarine during the rise and highstand of sea level. Above these estuarine deposits, the medium to coarse sands represent beach and shallow estuarine deposits during the high stand and initial fall of sea level after the high stand. In places, the sands are overlain by fine to medium sands with scattered organic-rich muddy laminae. These muddy laminae contain cold-climate flora, which represent deposition in bogs or ponds during a lowstand of sea level or are related to late Pleistocene periglacial deposition (Andres and Ramsey, 1996) and are not part of the Turtle Branch Formation.

North of the type area, the basal sands were deposited in streams that transitioned into sandy tidal flats (sand with silt and clay laminae) and beaches (well sorted coarse sands with granule and heavy mineral laminae). Organic silts and clays with some organic fragments, commonly found on the western side of the modern streams, were deposited in tidal marshes and swamps

Stratigraphic Relationships: The Turtle Branch Formation unconformably overlies the Beaverdam Formation. The base

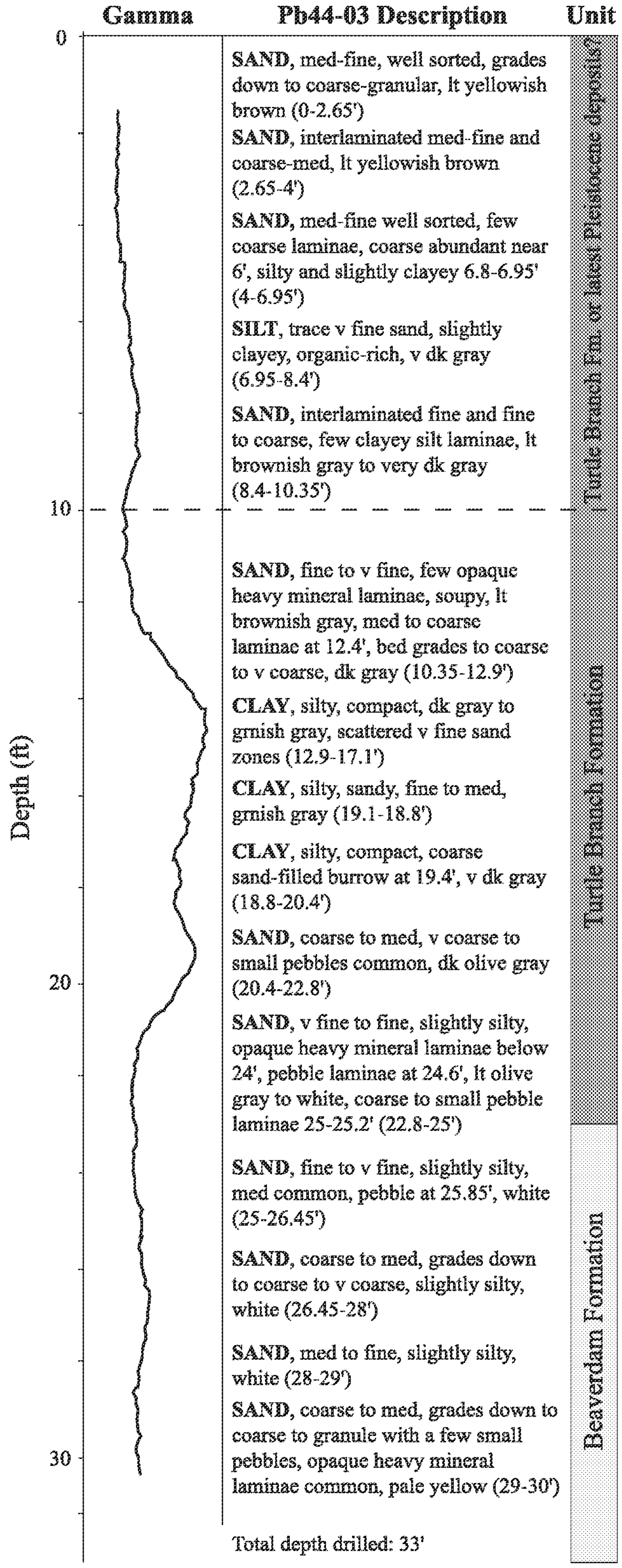

Figure 17. Type section (Pb44-03) for the Turtle Branch Formation. Geographic coordinates and land surface elevation are shown in Table 2. Core description from split spoon samples. Section above 10' (dashed line) could possibly be latest Pleistocene deposits. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

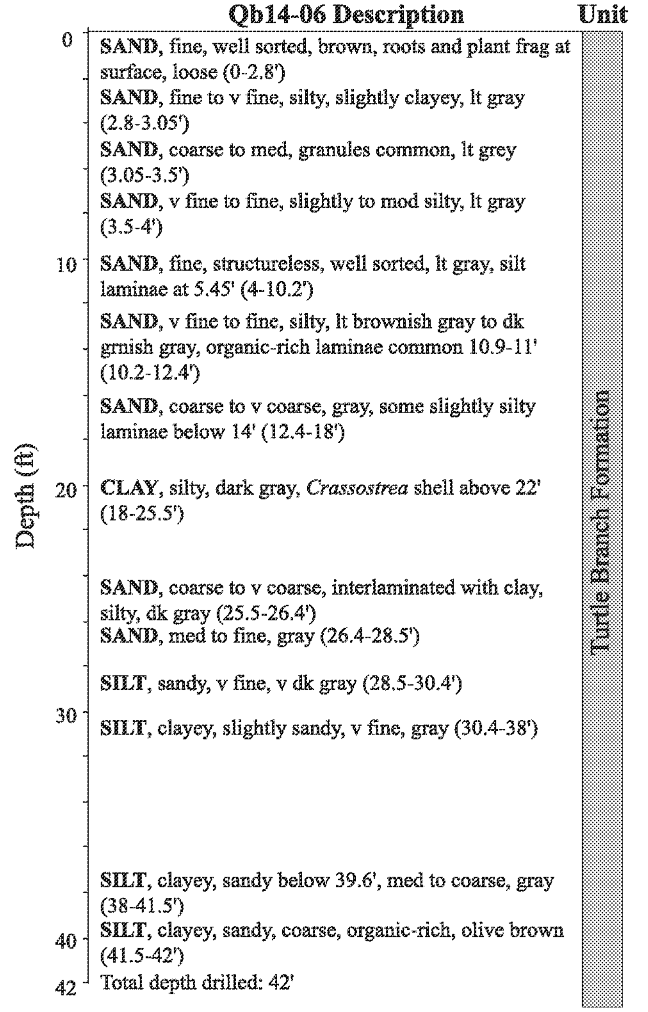

Figure 18. Reference section (Qb14-06) for the Turtle Branch Formation. Geographic coordinates and land surface elevation are shown in Table 2. Core described using split-spoon samples. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

of the unit is marked by a bed of clean, coarse sand with pebbles on top of the Beaverdam Formation. Where the basal sand layer is absent, the muds and clean sands of the Turtle Branch Formation contrast with the white silty sands of the Beaverdam. The Turtle Branch is unconformably overlain by the Kent Island Formation and by dunes of late Pleistocene to early Holocene age (Ramsey, 2010).

Palynology/Climate: The pollen from the Turtle Branch Formation is dominated by *Pinus* with variable amounts of *Quercus*. The climate is interpreted to have ranged from warm temperate to cool temperate.

Aminozones: One shell sample from the Nanticoke River Group can be assigned to aminozone II c, but the location from which the shell was collected cannot be determined with any degree of confidence.

Age: The Turtle Branch Formation is middle Pleistocene, approximately 400,000 yrs B.P. (MIS 11) and possibly 325,000 yrs B.P. (MIS 9) on the basis of stratigraphic and

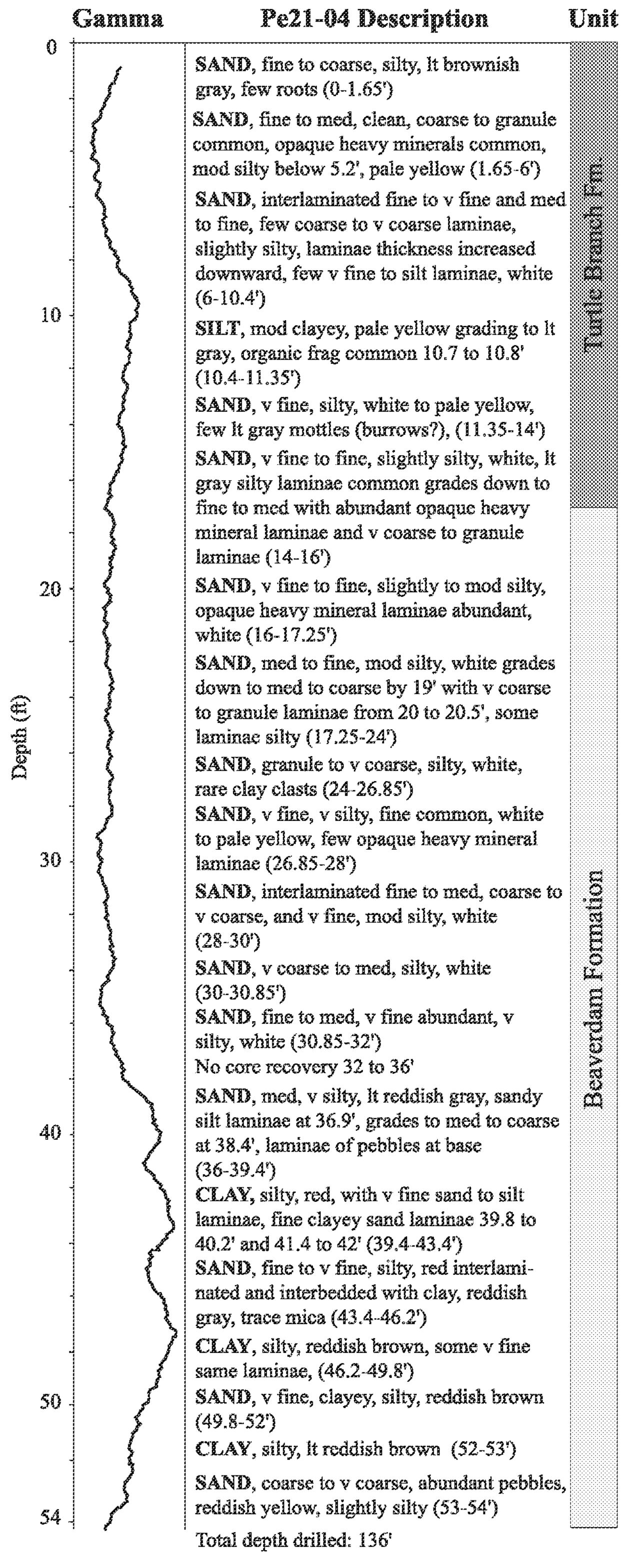

Figure 19. Reference section (Pe21-04) for the Turtle Branch Formation. Geographic coordinates and land surface elevation are shown in Table 2. Core descriptoin from split spoon samples. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

geomorphic positions and correlation of land surface elevation with the interglacial deposits of the Delaware Bay Group and Assawoman Bay Group.

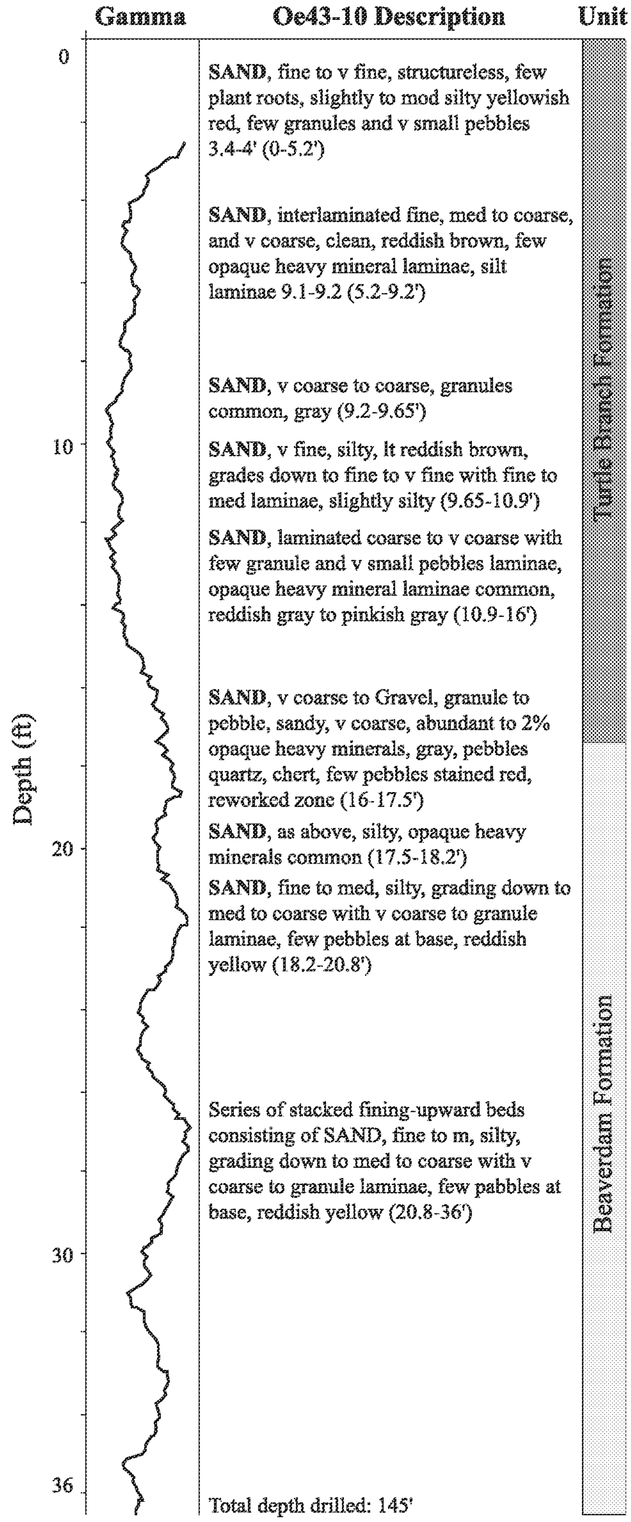

Figure 20. Reference section (Oe43-10) for the Turtle Branch Formation. Geographic coordinates and land surface elevation are shown in Table 2. Core description from split spoon samples. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

Kent Island Formation

The Kent Island Formation (Figs. 2, 16) is the youngest of the formations of the Nanticoke River Group.

Original reference: The Kent Island Formation was first described by Owens and Denny (1979a).

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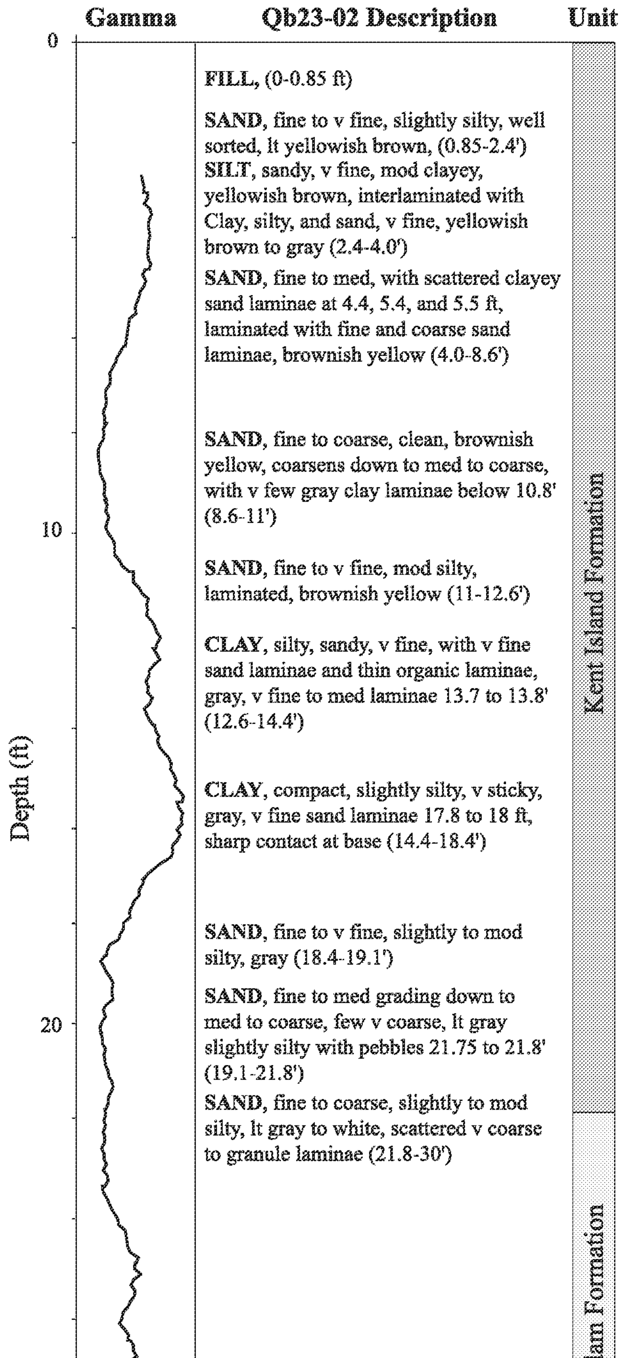

Figure 21. Reference section (Qb23-02) for the Kent Island Formation. Geographic coordinates and land surface elevation are shown in Table 2. Core description from split spoon samples. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

Type area: Owens and Denny (1979a) defined the type area for the Kent Island Formation as the bluffs on the north side of Kent Island, Maryland, along the Chester River.

Areal extent: In Delaware, the Kent Island Formatin extends along the margin of the Nanticoke River south of Seaford. It continues into adjacent Maryland (Owens and Denny, 1979a, b).

Reference section(s): Reference sections for the Kent Island Formation in Delaware include Qb23-02 (Fig. 21) and Qb14-05 (Fig. 22).

Description: Owens and Denny (1979a) named the Kent Island Formation for deposits bordering the Chesapeake Bay found underneath lowlands that ranged in elevation from 0 to 25 feet in elevation but most of the land surface area is less than 10 feet in elevation. These lowlands are bordered by a scarp with at toe at approximately 25 feet. In its type area, the Kent Island Formation was described as consisting of thick beds of loose, light-colored, cross-stratified sand overlying dark-colored massive to thinly laminated clay-silt. Pebbles as much as 10 cm (4 in.) in diameter occur in thin beds with the sand or as scattered clasts in both the sand and clay-silt. Locally, large tree stumps in growth position are encased in the clay-silt. Maximum thickness of the Kent Island was about 12 m (40 feet).

The Kent Island Formation in Delaware consists of a lower, light-gray to reddish-brown, coarse sand to pebble gravel with scattered organic silty clay lenses; a middle, gray, clayey silt to silty clay; and an upper fine to medium, brownish-yellow sand with scattered clay laminae. Rare lenses of shell, most commonly the oyster *Crassostrea,* are found where the middle clay is at its thickest. The thickness of the Kent Island Formation in Delaware ranges from 0 to 25 feet.

Previous work in the vicinity of the Nanticoke River (Jordan, 1964; Andres et al., 1995) documented the mineralogy of the sediments that are now assigned to Kent Island Formation. The sands are quartzose with up to 20 percent feldspar (Jordan, 1964; Andres et al., 1995). The gravel fraction composition is dominated by quartz and quartzite and up to 30 percent chert (Andres et al., 1995).

Geomorphology: The Kent Island Formation lies beneath a discontinuous, low-lying terrace along the Nanticoke River which has elevations ranging between 17 and 6 feet. The Kent Island Formation extends along the Nanticoke River to north of Seaford, Delaware (Fig. 2). It is possible to divide the Kent Island Formation into two units. The older unit has land surfaces between 17 and 12 feet. The younger unit, which occupies low-lying areas of less than 10 feet adjacent to the Nanticoke River.

Stream Networks: The Kent Island Formation is drained primarily by first order streams that originate at the scarp with the Turtle Branch Formation.

Depositional Environments: The Kent Island Formation is interpreted to have been deposited in fluvial to tidal stream to estuarine and estuarine beach environments. The lower sands are interpreted to be a basal transgressive lag of fluvial and swamp deposits that are replaced up section by estuarine mud. These estuarine deposits are overlain by intertidal and beach sands. The entire succession of deposits may not be present everywhere. Deposition and preservation of sediments within environments is dependent upon position in the estuary and the nature of the sediments of the underlying unit.

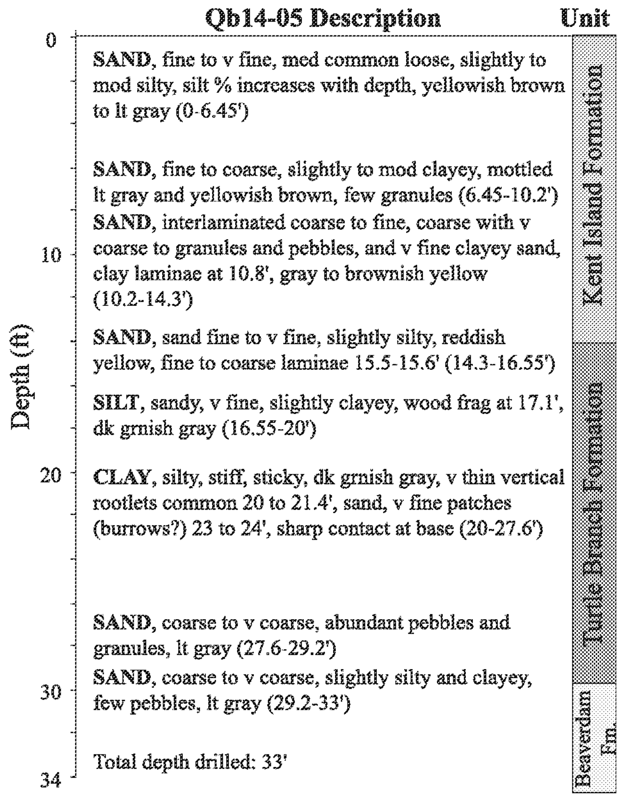

Figure 22. Reference section (Qb14-05) for the Kent Island Formation. Geographic coordinates and land surface elevation are shown in Table 2. Core description from split spoon samples. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

Stratigraphic Relationships: The Kent Island Formation unconformably overlies the Turtle Branch Formation, Beaverdam Formation, and perhaps the Cat Hill Formation in the Nanticoke River valley. The base of the Kent Island Formation is generally coarser than the underlying Beaverdam Formation and has brown, organic muds that are readily differentiated from the light-reddish-brown to white silty sands of the Beaverdam Formation. The Kent Island Formation is overlain by Holocene swamp and alluvial deposits along the Nanticoke River.

Palynology/Climate: The pollen from the Kent Island Formation is dominated by *Pinus* and *Quercus*. The climate is interpreted to be temperate.

Aminozones: Shell material from the Kent Island Formation has yielded racemization data that may be assigned either to aminozone IIb or IIa.

Age: The Kent Island Formation is late Pleistocene, approximately 120,000 yrs B.P. (MIS 5e) and 80,000 yrs B.P. (MIS 5a) on the basis of stratigraphic and geomorphic positions and correlation by land surface elevation with the interglacial deposits of the Delaware Bay Group and Assawoman Bay Group.

METHODS

The interglacial lithostratigraphic units of southern Delaware were not deposited independent of each other. Each rise and highstand of sea level left a record of deposition and erosion wherever the area was affected by sea level—along the ancestral Delaware Bay, Atlantic Coast, or Nanticoke River. The interglacial deposits are "bathtub rings" of deposits left behind at the margins of a basin by the interglacial sea-level highstand. In the case of southern Delaware, this basin is the Atlantic Ocean and the estuaries of Delaware Bay and Chesapeake Bay. Because the interglacial lithostratigraphic units are related to sea-level highstands, they have geomorphic expressions as terraces, which can be traced throughout southern Delaware. These terraces have definable ranges of land surface elevations and drainage patterns which are used as tools for geomorphic correlation of the underlying lithostratigraphic units. Coupled with age estimates from amino-acid racemization data from shell material and general climate data from pollen analyses, a coherent correlation for the lithostratigraphic units and a framework for their geologic history are discerned. The age estimates contribute to a framework of correlation of these units with the global middle to late Pleistocene sea-level marine isotope (MIS) record.

Using Terrace Elevations for Correlation

The middle to late Pleistocene record of highstands of sea level in the middle Atlantic Coastal Plain indicates that with each progressive rise and fall of sea level, subsequent sea level did not reach the height of the previous sea level (Oaks and DuBar, 1974; O'Neal and McGeary, 2002). The reasons for this phenomena are speculated by the author to be related to increasing amounts of ice retained in ice caps during interglacials throughout the middle to late Pleistocene (Walker and Lowe, 2007). These progressively lower highstands left a series of terraces that have progressively lower elevations toward the present coastline that are recognized regionally in the Atlantic Coastal Plain (Oaks and DuBar, 1974; Owens and Denny, 1979a; Mixon et al., 1989; Newell et al., 2001; O'Neal and McGeary, 2002; Weems and Lewis, 2007). These terraces are depositional "events" which are related to a particular rise and highstand of sea level. Elevations related to the highstand, then, become a proxy for correlation (assuming that post-depositional tectonic activity has not altered the terrace surfaces elevations).

The modern depositional system along the Delaware coast (Kraft et al., 1987) serves as a model for Pleistocene deposition and geomorphic expression. Nearshore sediments are deposited in estuarine bay bottom, tidal flat, and nearshore environments. Behind the coastal barrier, sediments are deposited in lagoonal bay bottom, tidal flat, and marsh environments. If sea level recedes, the depositional surface would be preserved as a gently seaward-sloping plain with the abandoned shoreline or back-barrier-marsh-upland contact preserved as a break in topography (scarp) (Fig. 23). Together, the abandoned shoreline (scarp) and the gently sloping depositional surface (tread) form a terrace (Fig. 23). The elevation of the intersection of the scarp and the tread (the toe of the scarp) approximates the elevation of the sea-level highstand.

With each highstand of sea level, older, topographically higher, landward units are partially removed prior to or

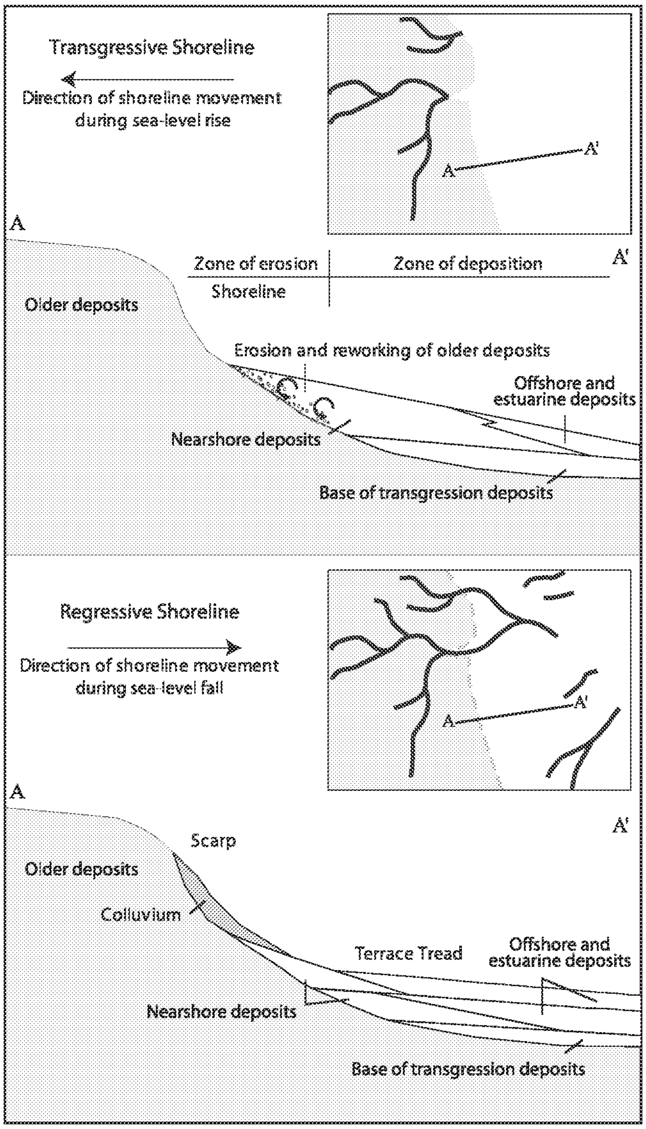

Figure 23. Schmatic representation of late Pleistocene terrace formation on the Coastal Plain of Delaware.

during deposition of the next younger unit by shoreline erosion, resulting in the younger unit being inset against the older unit (Fig. 24A, B). The terrace surfaces were not completely static features. Once sea level fell, new stream networks formed on the now exposed surfaces and integrated with older inland networks that cut across the terrace surface. Colluvium formed along the scarps (Fig. 24); where the scarps were steepest, small colluvial fans formed. During periods of cold climate, ponds and bogs develop in low areas, and dunes form and migrate across the terrace surface (Andres and Howard, 2000; Newell and Clark, 2008; Markewich et al., 2009) as shown in Fig. 24C.

Detailed surficial mapping of middle to late Pleistocene interglacial deposits in southern Delaware (Ramsey, 1993, 1997, 2001, 2003, 2005, 2007, 2009) has validated the concept of using land surface elevation as a tool in recognizing lithostratigraphic units. The relationships between land surface elevations and underlying lithostratigraphic units have been found to be consistent over quadrangle (1:24,000) and regional (1:100,000) scales. Similar ranges of elevations occur on all three lithostratigraphic groups. Because these elevations are associated with highstands of sea level, they can be used to correlate the interglacial lithostratigraphic units of southern Delaware. General ranges of terrace elevations were identified by visual inspection of existing topographic maps. These ranges were then selected in GIS and compared to existing geologic maps (Fig. 2). Correspondence exists between the terrace elevations and the distribution of the stratigraphic units (Fig. 25).

One cannot, however, determine solely by elevation the underlying stratigraphic unit. There are many locations where older deposits are at the land surface of a younger terrace tread where no deposition occurred or where erosion has removed the younger deposit. For example, the Beaverdam Formation is exposed on the terrace surface of the Scotts Corners Formation west of Rehoboth Bay (Fig. 2). In places, no erosional shoreline or scarp was formed during the rise of sea level, such as where a transgressive marsh encroached upon a relatively flat, older surface. The surface of the younger deposits merges with that of the older deposits without a topographic break between the two. There are also younger deposits such as dunes or ephemeral ponds related to deposition during periglacial conditions that have modified the terrace surfaces. Therefore, one cannot assume solely by use of land surface elevation which formation is found beneath the terrace surface.

Using Stream Networks for Correlation

Analysis of stream networks is a useful tool in correlation. Ramsey (1997) demonstrated that terrace surfaces in the Milford area have distinctive stream networks formed on them. Each terrace is drained by streams that begin near its landward scarp, cross the terrace, and connect with a primary or trunk stream. These trunk streams begin at the drainage divide and cross one or more terraces and are, downstream, the tidal rivers and bays that connect to Delaware Bay, the Atlantic Ocean, or Chesapeake Bay.

During sea-level highstand (Fig. 26A) the older streams not inundated by the rise of sea level were integrated into the base level (sea level) of the highstand. As sea level fell, stream formation began on newly exposed terrace surfaces at seeps and springs at the scarp (Fig. 26B). These streams cut their way across the exposed terrace flat either across the terrace surface or parallel to the scarp and intersected the older streams that cut a stream valley across the newly formed terrace as sea level fell. On the youngest terrace surfaces, some streams flow directly into the marsh or a tidal water body (Fig. 26B). These streams may have been tributary to a stream network now buried by sediment deposition associated with the present rise of sea level. With multiple rises and falls of sea level and the development of a series of terraces, stream networks record the evolution of drainage networks not as a single event or process. Rather, the stream networks developed in a series of events related to the rise of sea level, the formation of a terrace surface, the subsequent fall of sea level, the exposure of the terrace surface, and the development of a drainage network on the exposed surface.

Although Figures 26A and 26B are based on the streams tributary to Delaware Bay, similar networks are found along those tributary to the Atlantic Coast and Nanticoke River, but they are

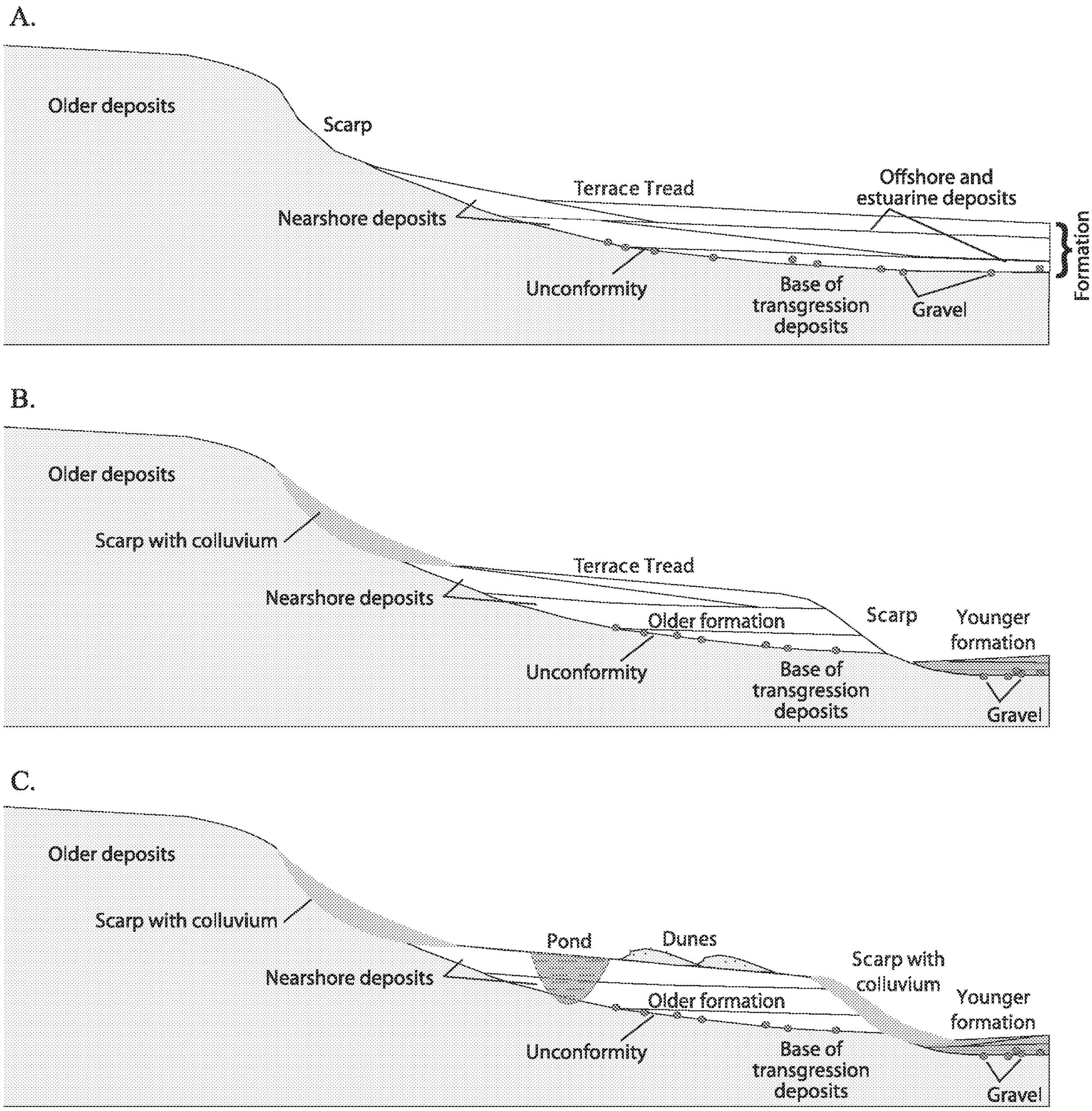

Figure 24. Schematic cross section of late Pleistocene geomorphic relationships. (A) deposition of terrace deposits onto older deposits. (B) inset of younger terrace into older terrace, (C) later modification of terraces with deposition in ponds and formation of dunes.

less well developed. These streams were farther away from a major meltwater discharge system and were not as heavily influenced by base-level adjustments to the system (White, 1979).

Recognition of the configuration of stream networks was used as a tool in correlation of stratigraphic units. An inspection of the stream networks in southern Delaware was conducted on both a regional and local scale (Figs. 2, 25). Using the concept of stream order (Ritter, 1978), first order streams were noted as to their location and position relative to terrace scarps. Stream order is a numerical ranking based on the number of tributaries contributing to a stream system. An order of 1 indicates a stream at its headwaters with no tributaries; stream order of 2 is a stream with 2 tributaries and so forth (Ritter, 1978, p. 176).

Extrapolating from the known relationships of the streams, terraces, and underlying lithostratigraphic units in the Milford area (Ramsey, 1997), similar geomorphic relationships can be identified throughout southern Delaware. These relationships are similar in terms of the configuration of first order streams, bounding scarps, and land surface elevations on adjacent formations. The general range of stream orders found on a particular terrace was also similar. These geomorphic characteristics indicate that the stream network formation developed in stages related to the exposure history of the surfaces upon which they were formed; therefore, the configuration of the stream networks can be used to correlate areas of similar stream network characteristics with the assumption that the areas had similar development and exposure histories.

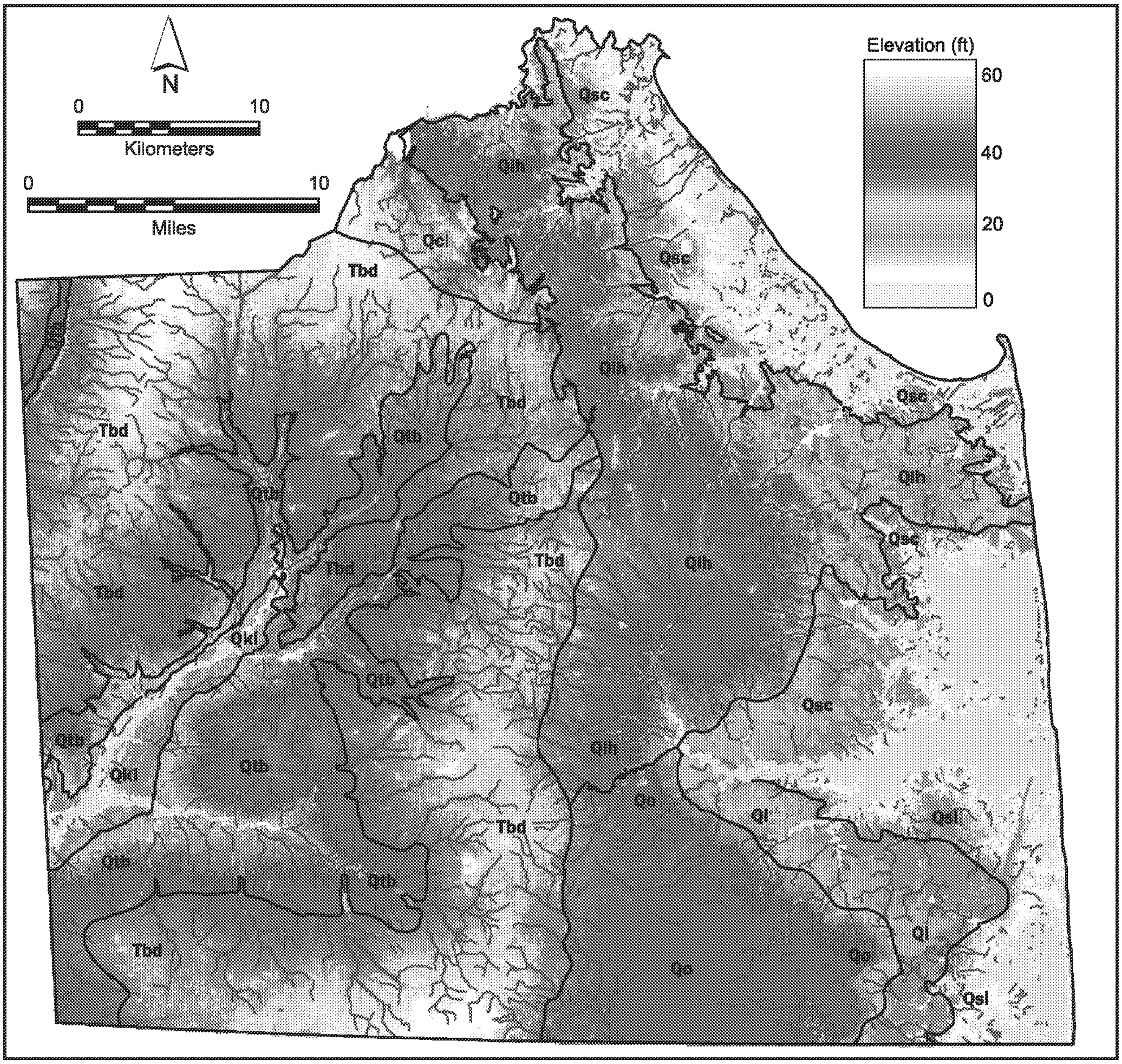

Figure 25. Digital elevation model (DEM) of Sussex County, (2005 Lidar), with color gradations and generalized boundaries of middle to late Pleistocene stratigraphic units and the Beaverdam Formation. The Walston and Cypress Swamp Formations (Fig. 2) are not shown. Man-made drainage systems (ditches) were removed from the basemap in order to highlight the original stream networks. The boundaries between stratigraphic units coincide with scarps seen in the DEM as color gradations over short distances. Many streams (shown as blue lines) have their origin near the scarps as discussed in the text. Note the higher density of streams on the Beaverdam Formation compared with the Lynch Heights Formations and their younger units. Note the continuity of elevations between the Omar and the similarity of elevation with the Turtle Branch Formation. Likewise, the Scotts Corners, Ironshire, and Sinepuxent Formations have similar elevation ranges with the Kent Island Formation. In central Sussex County, the Turtle Branch Formation crosses the drainage divide. This perhaps represents a MIS 11 high stand (> 20 meters, van Hengstum et al., 2009) that temporarily connected the ancestral Delaware and Chesapeake Bays. Tbd, Beaverdam Fm; Qo, Omar Fm.; Qlh, Lynch Heights Fm.; Qtb, Turtle Branch Fm.; Qsc, Scotts Corners Fm.; Qi, Ironshire Fm.; Qsi, Sinepuxent Fm.; Qki, Kent Island Fm.; Qcl, Columbia Fm.

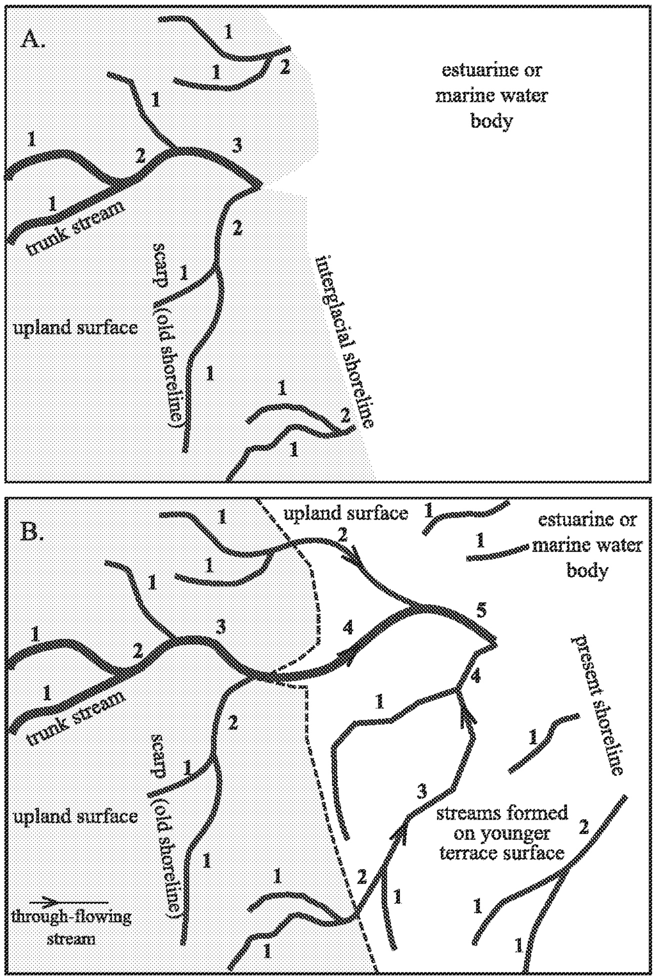

Figure 26. Conceptual model of stream network formation related to terrace formation. (A) stream configuration during interglacial high stand; (B) modern stream configuration. Numbers indicate stream order as discussed in the text.

Table 3. Geographic coordinates and land surface elevations for the amino-acid racemization samples. Northings and eastings are in meteres, UTM Zone 18. Elevations are in feet, NAVD 1988. Refer to Figure 27 for location of data points.

DGS ID	Land Surface Elevation	Northing	Easting	Formation
Pc25-04	26	4277317.5	448105.4	Kent Island
Qi54-02	5	4262615.0	490594.0	Omar
Qj22-06	5	4267903.5	494926.3	Sinepuxent
Qh41-a	18	4264312.0	478498.6	Omar
Ri13-a	10	4260856.4	488453.1	Omar
Qi51-04	5	4262582.0	486179.6	Omar
Nh44-a	15	4291364.5	482770.0	Lynch Heights (younger)
Oi25-39	20	4287115.1	492020.2	Lynch Heights (younger)
Pj22-05	-30	4277489.0	495681.4	Holocene/ rwk Sinepuxent
Qj12-01	-12	4269629.5	495217.8	Sinepuxent
Qj33-01	-18	4265745.5	495965.5	Holocene/ rwk Sinepuxent
*Ri25-01	-76	4258482.5	513965.8	Sinepuxent?

*Located offshore - not shown on map.

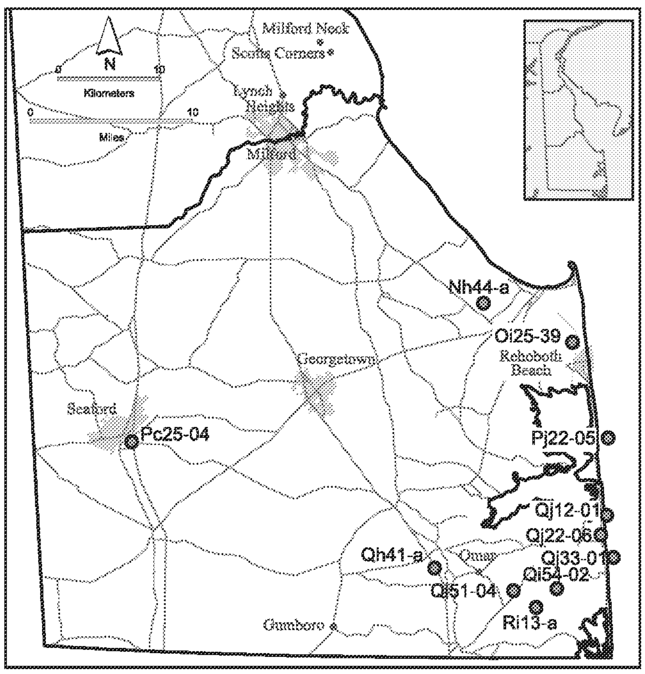

Figure 27. Location map for amino-acid racemization samples.

Determining Ages using Amino-Acid Racemization and Palynology

For the middle to late Pleistocene deposits of southern Delaware, aminostratigraphy provides a means of correlation between geologic units that is independent of the lithostratigraphy and geomorphology and is the primary method used for age correlation of the interglacial deposits of southern Delaware. Aminostratigraphy is a method by which relative ages of stratigraphic units can be determined from the geochemistry of fossil mollusk shells found within those deposits. Wehmiller, in Groot et al. (1990, p. 10), summarized aminostratigraphy as follows.

> "Aminostratigraphy relies upon the observation that amino-acids contained in fossilized skeletal organic matter (in mollusks, for example) undergo racemization during diagenesis. Racemization produces D- (or right-handed) amino-acids from the original L- (left-handed) amino-acids that produce biomineralization protein. The degree of racemization is determined by measurement of D/L values for one or more amino-acids in the total amino-acid mixture of a fossil. The D/L value starts at 0 in modern samples and reaches an equilibrium value (1.0 in most amino-acids) in about 1 to 2 million years at temperatures like those of the mid-Atlantic

region. The simplest approach to the use of amino-acid D/L data is as a stratigraphic tool, whereby relative ages are assigned to recognized clusters of D/L values (aminozones) from samples within a region of similar temperature histories."

Shell material is scarce in most and has not been found in some of the lithostratigraphic units that are the subject of this report. Shell material, where available (Table 3, Fig. 27), has been collected and analyzed for amino-acid D/L ratios. Grouping of clusters of D/L values within the middle Atlantic Coastal Plain is used to define aminozones (Wehmiller et al., 1988). The aminozones defined by Wehmiller et al. (1988), for the Middle Atlantic Region (Region II) were published in Groot et al. (1990) using data from Delaware and adjacent states. The aminozones are, from oldest to youngest; IId, IIc, IIb and IIa. Aminozones IId and IIc are middle Pleistocene in age, and aminozone IIb and IIa are late Pleistocene in age (Wehmiller in Groot et al., 1990). Additional data generated since 1990 are included in this report. Some of the stratigraphic unit assignments reported in Groot et al. (1990), have been revised on the basis of recent geologic mapping.

The pollen records the regional flora in adjustment with the climate at the time of the deposition of the sediment. Pollen within Pleistocene units record a range of climates from cold (near glacial) to warm temperate (like that of today) (Groot and Jordan, 1999; Groot et al., 1990). A general consensus exists that the flora, represented by the pollen, indicates that the units are Pleistocene in age and differ from deposits Miocene in age or older (Groot and Jordan, 1999). Groot et al. (1995) suggested that the ranges of different species of oak (*Quercus*) could be used to differentiate between older and younger deposits within the Pleistocene. This technique has yet to undergo rigorous testing with detailed sampling within or between units in Delaware to demonstrate its utility.

Published (Groot et al., 1990; Groot, 1991; Andres and Ramsey, 1996; Groot and Jordan, 1999) and unpublished DGS palynologic data are from scattered samples with limited stratigraphic context. Multiple pollen samples from a single core hole that provide information regarding assemblage variations within a unit are rare. For the middle to late Pleistocene interglacial deposits, the pollen that occur are similar, if not identical, to plant species and assemblages in eastern North America today. No major plant extinction or evolutionary events have occurred over this time period that can be of aid in the differentiation of units. The primary utility of the pollen assemblages is in characterizing the shifts between warm (interglacial) and cold (glacial) climates in terms of the general climate conditions (warm, cool, cold, wet, dry) during which they were deposited and in some cases whether deposition occurred in fresh or brackish water (P. McLaughlin, DGS, personal commun., 2008). General conclusions may be drawn from pollen data that strengthen age assignments and correlations using other methods.

Published pollen data (Groot et al., 1990; Groot, 1991; Andres and Ramsey, 1996; Groot and Jordan, 1999) were reviewed and summarized for dominant arboreal pollen taxa based on percentages of total pollen that characterize a particular stratigraphic unit as well as climatic interpretations based on the pollen assemblages. Unpublished data were reviewed for units that are not particularly well documented in terms of palynology. Taxa that appear to be persistent within a particular unit, which are rare or absent in adjacent units, were also noted. Some of the published stratigraphic unit assignments have been revised on the basis of recent geologic mapping. The available data and climatic interpretations regarding the palynology from the published and unpublished data with assignments of the data to the stratigraphic units of this report are presented in Table 4.

RESULTS

Correlations Using Terrace Elevations

Elevation is not a stand-alone criteria that can be used for determination of the underlying unit. Geologic mapping has shown that units older than the middle Pleistocene, especially the Beaverdam Formation, occur at the land surface of younger terraces. For example, west of the Nanticoke River, broad flats are underlain by the Beaverdam Formation at elevations where one would expect younger Pleistocene deposits such as the Turtle Branch Formation (Fig. 25). In these areas, the energy regime may have been more erosional than depositional, the sediment supply may not have been available for deposition of sediment, or the younger deposits may have been removed by subsequent erosion.

Correlation of units by elevation, then, is expressed in terms of ranges of elevations at which the Pleistocene deposits occur. The upper limit of a range is the highest elevation at which the deposit is found at the land surface and the lower limit of a range is the lowest elevation at which the deposit is found at the land surface. Highly generalized boundaries of the Pleistocene stratigraphic units are shown in Figure 25. This figure should not be used to determine site-specific geology. These boundaries will likely change as more detailed mapping is conducted. The elevation ranges of the Pleistocene units and terraces are consistent throughout the study area and are a valid guide for correlation of stratigraphic units (Table 5).

Three broad ranges of elevations can be discerned: 45-25 ft., 20-15 ft., and 12-0 ft. (Fig. 25). The Delaware Bay Group terraces and the Assawoman Bay Group terraces are consistent in elevation ranges. The surfaces of the Lynch Heights Formation (older and younger) and Omar Formation have the same general range of elevations (45-25 ft.). The terrace surfaces of the older Scotts Corners Formation and Ironshire Formation are between 20 and 15 feet in elevation. The younger Scotts Corners Formation and the Sinepuxent Formation have terrace surface elevations between 10 feet and sea level.

The ranges of elevations for the Nanticoke River Group terraces differ in the upper ranges of terrace elevations from the other two groups, but in general, the Turtle Branch elevations (37-25 ft) are similar to those of the Lynch Heights and Omar Formations (45-25 ft), and those of the Kent Island Formation (17-8 ft) are similar to the older Scotts Corners and Ironshire Formations. Another, lower surface on the Kent Island Formation occurs between 10 and 6 feet and has similar elevations to those of the younger Scotts Corners Formation and the Sinepuxent Formation There are not

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Table 4. Summary of pollen assemblages of late Pleistocene units of southern Delaware with samples reassigned stratigraphically per this report (Groot et al., 1990; Andres and Ramsey, 1996, Groot and Jordan, 1999).

	Major Pollen Components	Additional Important Pollen Components	Climate and Depositional Environment
Lynch Heights Formation	*Pinus* abundant *Quercus* common to uncommon *Carya* common *Betula* common to present	*Picea* present <50% of samples Graminae present >75% of samples *Liquidambar* absent *Tsuga* rare in <10% of samples	Cool temperate to temperate Estuarine, marsh, and lagoon
Comments: 13 samples; older and younger Lynch Heights not differentiated; Graminae now referred to as Poaceae			
Scotts Corners Formation	*Pinus* abundant *Quercus* abundant to common *Carya* common *Betula* common to abundant	*Picea* present in some samples Graminae present to common in 50% of samples *Liquidambar* present to common in >75% samples *Tsuga* present to uncommon	Warm temperate Estuarine and marsh
Comments: 22 samples; older and younger Scotts Corners not differentiated; Graminae now referred to as Poaceae			
Omar Formation	*Pinus* abundant *Quercus* abudnant to uncommon *Carya* common	*Picea* present in some samples *Tsuga* present to uncommon	Temperate to warm termperate Few samples within unit indicate cool climate Estuarine, lagoon, marsh, and swamp
Comments: 25 samples; older Omar that contains exotic pollen (Groot and Jordan, 1999) excluded from summary			
Ironshire Formation	*Pinus* abundant *Quercus* abudnant	*Picea* present but rare *Betula* present to common TCT common	Temperate to cool temperate Estuarine with marine influence and marsh
Comment: 2 samples; TCT = Taxodiaceae-Cuprescaceae-Taxaceae			
Sinepuxant Formation	*Pinus* abundant *Quercus* uncommon *Carya* uncommon	*Picea* common *Alnus* common	Cool Estuarine with marine influence
Comment: 6 samples			
Turtle Branch Formation	*Pinus* abundant *Quercus* abudnant to rare *Carya* abundant to common	*Picea* absent *Tsuga* rare to absent *Pinus* dominant with common to rare *Quercus* in 40% of samples	Warm temperate to cool temperate Estuarine to marsh
Comment: 25 samples			
Kent Island Formation	*Pinus* abundant *Quercus* abundant	*Picea* very rare to absent *Alnus* common *Carya* common *Tsuga* rare	Temperate Estuarine to marsh
Comment: 5 samples			

enough collaborative lithostratigraphic data at present to subdivide the Kent Island Formation into older and younger units.

Correlations Using Stream Networks

The distribution of the middle to late Pleistocene stratigraphic units of Sussex County with an overlay of the streams is shown in Figures 2 and 25. The oldest exposed surface on the Beaverdam Formation has more streams on it than does the youngest surface on the Scotts Corners Formation. Many stream networks are restricted to the map areas of individual stratigraphic units (terrace treads) or are tributaries. This observation is in agreement with a model of stream network formation on the terrace treads exposed after fall of sea level.

It has been observed that stream networks and their relationships to terraces on which they are formed can be used for correlation (Ramsey, 1997). Three observations from Table 5 summarize their utility for correlation.

First, the youngest stratigraphic units are drained by small, first order streams that flow directly into modern depositional environments (Fig. 25). Some, but not all, of these streams have their headwaters near the scarp separating these youngest units from older units landward. On the younger Scotts Corners Formation, these streams drain directly into marshes along Delaware Bay or Rehoboth Bay. On the Sinepuxent Formation, the streams drain into marshes bordering Little Assawoman or Assawoman Bays or directly into the bays themselves. On the Kent Island Formation, the streams flow directly into the Nanticoke River or through swamps or marshes that border the river. The streams

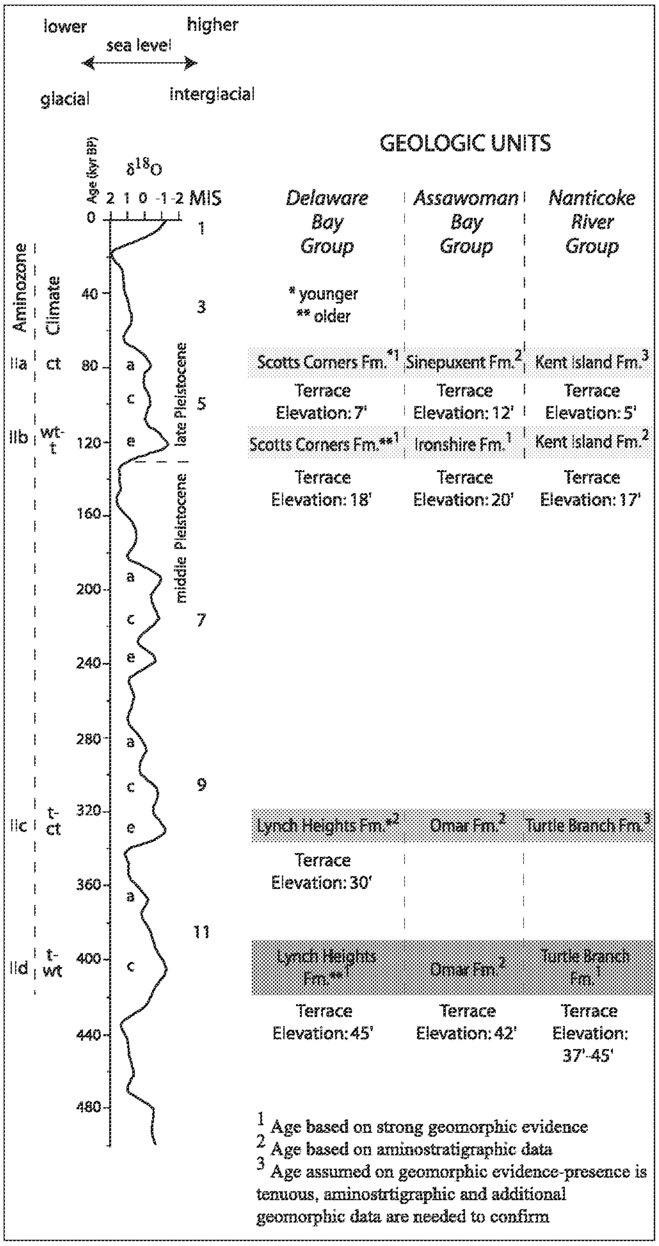

Figure 28. Summary of the late Pleistocene stratigraphic units of Delaware. Aminozones, this report; Climate - ct, cool temperature; wt-t, warm temperature; t-wt temperate to warm temperate from Groot et al., 1990 and Groot, 1991; Oxygen Isotope Curve from Tzedakis, et al., 2001; MIS, Marine Isotope Stage 1; Walker et al.,[1] 2009, Stages 6-11; Bowen, 1978; Stages 2-5, 5a-5e; Cutler et al., 2003.

connected to a larger drainage network and are now buried by recent marsh and swamp sediments that were deposited during the Holocene rise in sea level (Kraft et al., 1987). The streams were formed during the sea-level lowstand between the deposition of the stratigraphic units that they drain (MIS 5a) and the Holocene rise of sea level (Kraft et al., 1987).

Second, the oldest formations (Lynch Heights, Omar, and Turtle Branch) tend to have higher-order streams developed on their surfaces (Fig. 25). This suggests that after the initial formation of streams on the terraces, the drainage networks continued to develop during subsequent changes of sea level. The streams on these older units are completely integrated into the network of through-flowing streams that connects the upland interfluve surface of the Beaverdam Formation to the modern depositional system. The first-order streams on these formations primarily have their origins near the bounding scarp with the Beaverdam Formation or the Columbia Formation in northeast Sussex County at a break in topography (scarp) between 50 and 45 feet. The break in topography between the Turtle Branch Formation and the Beaverdam Formation is not as well developed.

Third, the older Scotts Corners and Ironshire Formations display stream network characteristics intermediate between older and younger units by having networks of first and second order streams (Fig. 25). The majority of these streams originate at the scarp that separates the surface that they drain and that of an older unit landward. This scarp is well developed between the Scotts Corners and Lynch Heights Formations along the entire length of Delaware Bay. It is less well developed, but still recognizable between the Ironshire and Omar Formations. The Ironshire Formation is of limited areal extent in Delaware. The pattern of stream networks is better developed in adjacent Maryland where the unit is more extensive (Owens and Denny, 1978). This intermediate pattern is not nearly as well developed along the Nanticoke River but is discernable on the upper portions of the Kent Island Formation.

Age Determinations

Amino-acid racemization analysis yielded data that indicated aminozones IId, IIc, and IIa are present in southern Delaware (Tables 5, 6). Aminozone IIb is absent or represented by a single sample from the Kent Island Formation. With the exception of Pepper Creek, the Omar Formation is placed in aminozone IId. The younger Lynch Heights Formation and the Omar Formation at Pepper Creek are placed in aminozone IIc. The Sinepuxent Formation is placed in aminozone IIa. The Kent Island Formation is associated with aminozone IIa or IIb. One sample not included in Table 5 came from the Nanticoke River Group (Qc24-c; DGS unpublished data). The sample was collected during the 1960s, and a precise location cannot be determined. A shell was analyzed and yielded racemization numbers that would be assigned to aminozone IIc (J. F. Wehmiller, personal commun., 2009). This sample likely came from the Turtle Branch Formation.

Samples from Nh44-a (Table 6), which were previously assigned to the Omar Formation and placed in aminozone IIb, are now considered part of the younger Lynch Heights Formation. Reanalysis of the D/L values places the samples in aminozone IIc (J. F. Wehmiller, personal commun., 2009). Samples from a core hole in Cape Henlopen State Park west of the Lewes and Rehoboth Canal (Oi25-39) have also yielded ratios in aminozone IIc (J. F. Wehmiller, personal commun., published in this report). Likewise, samples from Qh41-a (Omar Formation, Pepper Creek Ditch site of Groot et al., 1990; and described by Jordan, 1974) are now assigned to aminozone IIc, but the data are problematic due to poor sample preservation (J. F. Wehmiller, personal commun., 2008).

Table 5. Summary of correlation of data for stratigraphic units discussed in this report.

	Land Surface Elev. (ft)	Stream Networks	Climate and Depositional Environment	Aminozones
Lynch Heights Formation (older)	45-40	1st and 2nd order; 3rd order (few)	Cool temperate to temperate Estuarine, marsh, and lagoon	No data
Lynch Heights Formation (younger)	30-25	1st and 2nd order	Not differentiated from above	IIc
Scotts Corners Formation (older)	18-10	1st and 2nd order; 1st order originate at toe of scarp with Lynch Heights Fm.	Warm temperate Estuarine and marsh	No data
Scotts Corners Formation (younger)	7-0	1st order (primarily); drain directly into modern marshes or Rehoboth Bay	Not differentiated from above	No data
Omar Formation	42-25	1st, 2nd, and 3rd order; ditching obscures original networks	Temperate to warm termperate Few samples within unit indicate cool climate Estuarine, lagoon, marsh, and swamp	IId, IIc
Ironshire Formation	20-15	1st and 2nd order; 1st order originate at toe of scarp with Omar Fm.	Temperate to cool temperate Estuarine with marine influence and marsh	No data
Sinepuxent Formation	12-0	1st order that originate at toe of scarp with Ironshire Fm. and drain into Little Assawoman and Assawoman Bays; lower reaches are drowned by bays	Cool Estuarine with marine influence	IIa
Turtle Branch Formation	37-25	1st, 2nd, and 3rd order; 4th order (few); network modified by ditching	Warm temperate to cool temperate Estuarine to marsh	No data
Kent Island Formation	17-8, another possibly 5-0	1st order (primarily) that originate at toe of scarp with Turtle Branch Fm. and drain directly into the Nanticoke River	Temperate Estuarine to marsh	IIa or II b

The most recognizable interglacial unit in terms of a palynological signature is the Sinepuxent Formation. The Sinepuxent Formation has more *Picea* (spruce) than any of the other units. *Picea* is an indicator of cool climate, and where abundant with little to no temperate flora (such as *Quercus* (oak) or *Carya* (hickory)), is indicative of a cold climate associated with glacial or near glacial conditions (Groot et al., 1990; McLaughlin et al., 2008). The data for the pollen samples that could potentially be assigned to the younger Scotts Corners Formation (Ramsey, 1997) or the Kent Island Formation (Andres and Ramsey, 1996; Groot and Jordan, 1999) do not show this cool signal. More samples are needed from these units to determine if they have a similar or different pollen flora than the Sinepuxent Formation.

Other significant components of the pollen from the middle and late Pleistocene units are summarized in Table 5 and in the appendix. The pollen assemblages are similar for all of the units. Unless other data from more continuous sections become available, the pollen data indicate the range of assemblages that could be expected for the interglacial deposits, but the data cannot be used for correlation of units or recognition of any particular stratigraphic unit.

DISCUSSION

Correlation of Delaware Middle to Late Pleistocene Interglacial Deposits with the Global MIS Record

Sea-level curves based on marine oxygen isotope curves (Bintanja et al., 2005; Tzedakis et al., 2001; Lisiecki and Raymo, 2005) and uranium-series dating of coral reef terraces or low-stand deposits (Chappell et al., 1996) have

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Table 6. Summary of amino-acid racemization data from Delaware.

DGSID	UDAMS	Locality Abbrev.	Locality Name	Strat. Unit	Amino-zone	AAR Data	D/L Leu	AIL/ILE	Ref.
Pc25-04	05011	NRSD	Nanticoke Rvr.- Seaford	K. I.	IIa/IIb	*Crassostrea*	0.23	0.23	1
Qi54-02	05033	MC-4	Miller Crk.	Omar	IId	*Crassostrea*	0.45		2
Qj22-06	05034	Beth	Bethany Bch.	Snpxnt.	IIa	*Mulinia*	0.22		3
Qh41-a	05045	PCD	Pepper Crk. Ditch	Omar	IIc	*Mercenaria*	0.33		1,4
Ri13-a	05048	DCAD	Dirickson Crk. Ag. Ditch	Omar	IId	*Mercenaria*	0.53		1,4
Qi51-04	05080	ROX	Roxana	Omar	IId	*Crassostrea*		0.43	5
Nh44-a	05089	LBND	Lobiondo Property	L. H. (yngr)	IIc	*Mercenaria*		0.33	5
Pj22-05	05219	JCK-F3-81	Offshore old USCG Stn.	Holcn., rwrkd Snpxnt.	IIa	*Spisula or Mulinia*		0.15	6
Qj12-01	05040	JCK-H1-81	Offshore Cedar Neck	Snpxnt.	IIa	*Mulinia*	0.165		7
Qj33-01	05222	JCK-I2-81	Offshore Bethany Bch.	Holcn., rwrkd Snpxnt.	IIa	*Spisula*		0.17	6
Rl25-01	05130	DGS-92-16	Offshore Fenwick	Snpxnt.?	IIa	*Astarte*		0.15	6
Rl25-01	05130	DGS-92-16	Offshore Fenwick	Snpxnt.?	IIa,	*Mercenaria*		0.18	6
Rl25-01					rwrkd IIc	(one specimen		0.31	
Rl25-01					/IId	each)		0.46	
Oi25-39	05228	REB-3	Cape Henlopen St. Pk.	L.H. (yngr)	IIc	*Mulinia*	0.363	0.324	this pub.
Oi25-39						(one specimen	0.376	0.361	
Oi25-39						each)	0.363	0.236	
Oi25-39							0.393	0.292	
Oi25-39							0.406		

NOTES

UDAMS = University of Delaware Amino Stratigraphy Location No.
K. I. = Kent Island Formation
Snpxnt. = Sinepuxant Formation
L. H. = Lynch Heights Formation
Holcn. = Holocene
AAR Data = genera analyzed
D/L LEU = D/L leucine values
AILE/ILE = D-alloisoleucine/L-isoleucine

1. Belknap, 1979
2. Demarest, 1981
3. McDonald, 1981
4. Wehmiller et al., 1988
5. Groot et al., 1990
6. Williams, 1999
7. unpublished Belknap data

been the framework for dating late Pleistocene deposits worldwide as well as in the Atlantic Coastal Plain (e.g., Wehmiller et al., 2004; Mallinson et al., 2008). The marine oxygen isotope (MIS) curve (Fig. 28) is an accepted proxy for the relative rise and fall of sea level related to the amount of water stored in the continental ice sheets during glacial and interglacial periods of the Pleistocene. The age range assigned to each stage on the MIS curve is shown in Figure 28 and Table 1. Even-numbered stages are glacial periods when sea level was low; odd-numbered stages are interglacial periods when sea level was high. The warmest periods, when Northern Hemisphere temperatures were considered to be higher than present, are at 400,000 yrs B.P. (MIS 11), 330,000 yrs B.P. (MIS 9), and 120,000 yrs B.P. (MIS 5e) (Bintanja et al., 2005). Sea levels during MIS 5e are thought to be higher than present sea level (Cutler et al., 2003).

The correlation of the late Pleistocene deposits of Delaware with the MIS curve are shown in Figure 28. The correlation is developed on the relative ages of the units, aminostratigraphic data, and climate data as indicated by the pollen record. Four significant late Pleistocene depositional phases related to highstands of sea level are interpreted in the Delaware Coastal Plain.

The older portions of the Lynch Heights, Omar, and Turtle Branch Formations are assigned to MIS 11 (approximately 400,000 yrs B.P.). This assignment fits with the aminozones and numerical age estimates of the Omar Formation for aminozone IId. MIS 11 is the longest of the middle Pleistocene interglacials lasting about 60 ka (Droxler and Farrell, 2000). The length of the interglacial may explain some of the climatic variations found within the Omar Formation (Groot et al., 1990; Groot and Jordan, 1999). MIS 11 records indicate that within the interglacial there was a warm period followed by a cooler interval, which was then followed by another warm period (Ashton et al., 2008; Tzedakis et al., 2001). More importantly, the longer time span of the interglacial may explain the more extensive deposition both in terms of the thickness and geographic distribution of the Lynch Heights, Omar, and Turtle Branch Formations as compared to younger interglacial units. MIS 11 also had high sea levels up to 20 m (66 ft) above present sea level (Droxler and Farrell, 2000; van Hengstum et al., 2009). Although the surfaces of the units in Delaware do not reach heights of 66 ft, they are the highest of the interglacial deposits.

The younger Lynch Heights Formation and a portion of the Omar Formation are correlated with MIS 9 (330,000 yrs B.P.). Both of these units have samples that are included in aminozone IIc (Nh44-a and Oi25-39, and Qh41-a, respectively). The correlation of aminozone IIc with MIS 9 is consistent with regional aminostratigraphy (J. F. Wehmiller, personal commun., 2008). MIS 9 was, along with MIS 5e, the warmest of the interglacials (Droxler and Farrell, 2000). Sea-level estimates for MIS 9 range from 16 ft (5 m) from New Jersey terraces (O'Neal and McGeary, 2002) to 10 ft (3 m) for the Bahamas (Hearty and Kaufman (2000). There are not enough pollen data from the younger Lynch Heights and Omar Formations to discern if a warm signal is present in the pollen record.

Although there have been published reports that there are MIS 7 deposits on the Delmarva Peninsula (Newell and Clark, 2008; Hobbs, 2004; and Oertel and Foyle, 1995), no deposits are assigned to MIS 7 (Fig. 28) in this report. The temptation is to match subsequently older deposits with consecutive highstands. In such a scenario, the younger part of the Lynch Heights, Omar, and Turtle Branch Formations would be correlated with MIS 7 and the older parts with MIS 9. The oxygen isotope curve in Figure 28 does not show significant differences in sea level between MIS11 and MIS 9 and between MIS 5a and MIS 7. Sea level during MIS 7, however, is not considered to have been as high as during MIS 9 or 5a. At highstand, MIS 7 was between -9 to -20 m (-30 to -66 feet) relative to present sea level (Hearty, 2002; Bard et al., 2002). This would make it unlikely that any MIS 7 deposits would be present in Delaware's coastal plain. If present, they would be found at depth beneath the Ironshire or Sinepuxent Formations. There is no indication that such deposits exist.

The older Scotts Corners, Ironshire, and Kent Island Formations are assigned to the late Pleistocene MIS 5e. The well-developed scarp between these units and older interglacial units landward is identical in geomorphic position to that of the Suffolk Scarp found throughout the Atlantic Coastal Plain (Oaks and DuBar, 1974). The Suffolk Scarp elsewhere separates MIS 5 deposits to the east from older deposits to the west (Mirecki et al., 1995; Mixon, 1985). The older Scotts Corners and Ironshire Formations are lacking in shell material that could be used for amino-acid racemization analysis. The Kent Island Formation has a single shell sample that could either be assigned to MIS 5e or 5a (aminozone IIb or IIa, respectively). MIS 5e is considered to be among the warmest of the interglacials (Droxler and Farrell, 2000), and some of the pollen samples from the Scotts Corners Formation indicate warm, temperate conditions, but samples are not abundant enough to draw significant comparisons at this time.

The younger Scotts Corners and Sinepuxent Formations, and perhaps part of the Kent Island Formation are younger than MIS 5e. The possibilities for the period of deposition of these units could be MIS 5c or MIS 5a. This assignment fits with numerical age estimates for shells from the Sinepuxent Formation and possibly the Kent Island Formation (aminozone IIa, 75-130,000 yrs B.P.) (Groot et al., 1990; Table 4 this report). There are widespread deposits of similar ages all along the Atlantic Coastal Plain that have been dated with uranium-series coral ages and with amino-acid racemization age estimates (aminozone IIa) to that time period (Wehmiller et al., 2004). These deposits are partially above present sea level with surfaces between 0 and 18 feet (0 and 6 meters) that are within the range of elevations found on the Sinepuxent. The pollen record for the Sinepuxent indicates a climate cooler than present which would be consistent with MIS 5a (Cutler et al., 2003). Sea-level maxima for MIS 5a have been measured to be about 10 meters (33 feet) below present for MIS 5a (Cutler et al., 2003), but the height of this highstand is uncertain with multiple uranium series dates indicating it approached that of MIS 5e throughout the Atlantic Coastal Plain (Wehmiller et al., 2004).

Owens and Denny (1979a) considered the Sinepuxent to be mid-Wisconsinan (MIS 3), based on radiocarbon dates from peat located near the top of the unit and shell from beneath a peat on Assateague Island, Maryland. Owens and Denny (1979a) note that the reliability of the radiocarbon dates is in question. Peats with ages of +/- 30,000 yrs B.P. have been documented from multiple localities in Delaware (Ramsey and Baxter, 1996; Andres and Howard, 2000; unpublished DGS data) and are thought to be related to cold climate pond deposition, not estuarine marshes related to a highstand of sea level. Mallinson et al. (2008) mapped MIS 3 shorelines above present sea level in North Carolina based on OSL (optically stimulated luminescence) age estimates. Most reliable estimates place the height of MIS 3 highstand at -40 m (-131 ft) relative to present sea level (Lambeck et al., 2002).

Correlation of the interglacial deposits of southern Delaware with the MIS record is consistent with published records in the region. Colman and Mixon (1988) correlated Chesapeake Bay region paleochannels (crossing beneath the Delmarva Peninsula carved during glacial periods) and fill deposits (interglacial deposits forming the surficial deposits of the Delmarva Peninsula) with the MIS record. They assigned the Nassawadox Formation (Mixon, 1985) to MIS 5 and noted that there were "early" and "late" components to the unit based on amino-acid racemization data and uranium-series ages. The Nassawadox Formation was considered by Mixon (1985) to be younger than the Omar Formation. The early and late designations likely indicate separate depositional events (MIS 5e and MIS 5a) (Wehmiller et al., 2004). Colman and Mixon (1988) also recognized the Omar Formation (Accomack Member as assigned by Mixon, 1985), which they assigned to either MIS 7 or MIS 11 (and not ruling out MIS 13) with MIS 11 being the more likely option.

Oertel and Foyle (1995), and Hobbs (2004) recognized periods of deposition in the lower Chesapeake Bay region associated with MIS 11, 9, 7 (possibly), and 5 (two or three separate periods). For units located in the southernmost Delmarva Peninsula, it is difficult to make direct comparisons between the MIS assignments of Colman and Mixon (1988), Oertel and Foyle (1995) and Hobbs (2004) with those of this report; however, the ranges of MIS assignments are not contradictory. Regional correlation of the interglacial stratigraphic units throughout the Delmarva Peninsula is needed in order to make this comparison possible.

O'Neal and McGeary (2002) recognized six unconformity-bounded middle to late Pleistocene units in the Cape May Formation of the Coastal Plain of New Jersey along the margins of Delaware Bay, which they considered correlative with the Delaware Bay Group in Delaware. They correlated their unit 1 with MIS 13 or early MIS 11, unit 2 with early MIS 11, unit 3 with mid-MIS 11, unit 4 with late MIS 11, unit 5 with MIS 9, no unit correlated with MIS 7, unit 5 with early MIS 5e, and unit 6 with late MIS 5e. Again, it is difficult to make direct comparisons with the units in Delaware. Unit 4, correlated with MIS 11, is reported to have deposits up to 16 m (52 ft) above sea level, which is slightly higher in

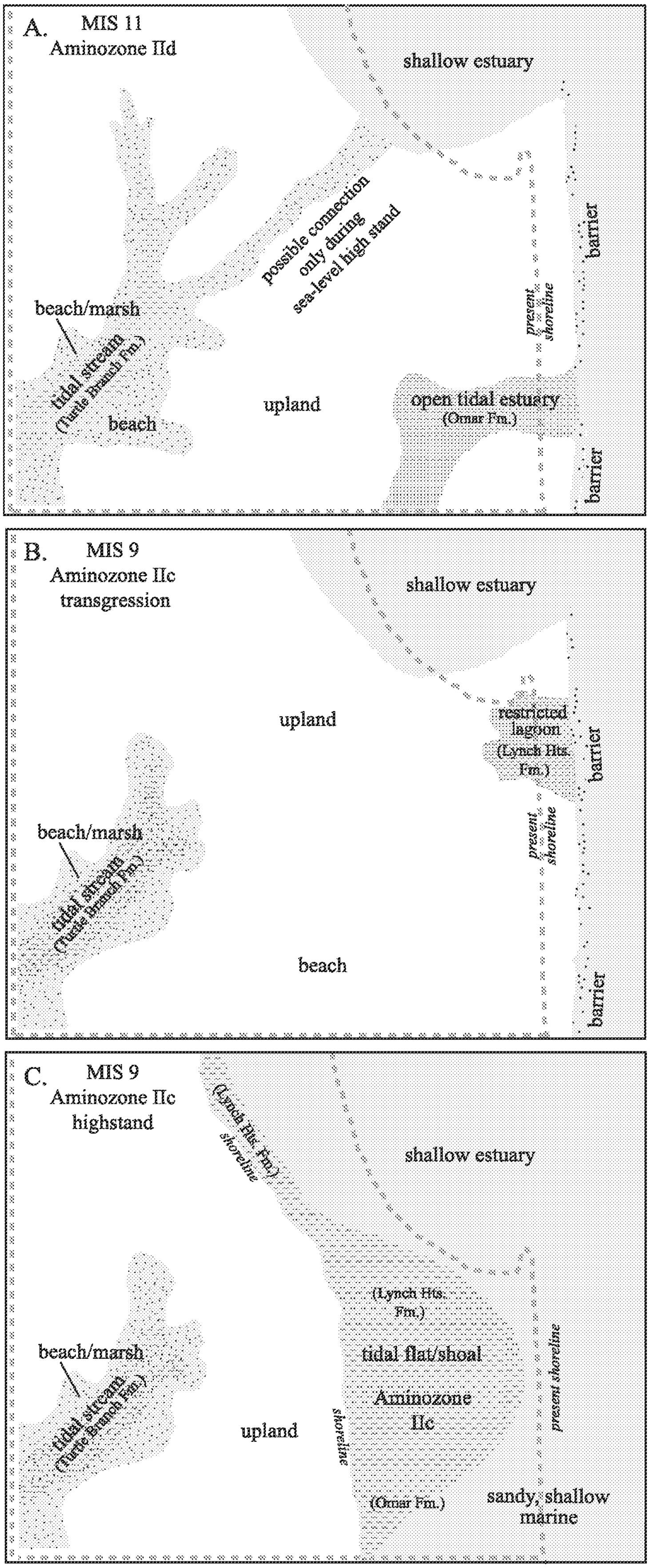

Figure 29. Conceptual models of deposition during (A) MIS 11 (older Lynch Heights, Omar, and Turtle Branch Formations); (B) MIS 9 transgression (younger Lynch Heights, Omar , and Turtle Branch Formations; and (C) MIS 9 high stand (younger Lynch Heights, Omar, and Turtle Branch Formations). Transgressive environments (B) were much like that of today with lagoon and estuarine environments along the ancestral Atlantic Coast, shallow estuarine environments along the ancestral Delaware Bay coast, and tidal stream environments along the ancestral Nanticoke River tributary to an ancestral Chesapeake Bay. High-stand environments (A, C) included a sandy shoreline along the ancestral Atlantic and Delaware Bay coastlines, a shallow tidal connection between the shallow Delaware Bay estuary and the Nanticoke estuary and sandy shorelines along the Nanticoke tidal stream. The lagoons along the Atlantic and Delaware Bay shorelines (A, B) were completely filled with sediment and transgressed by the shoreline (C). Dashed line represents the present Delaware/Maryland state boundary and the Atlantic Coast.

elevation, but in the range of the Lynch Heights Formation correlated in this report with MIS 11. Unit 6, correlated with MIS 5e, is found up to 5 m (16 ft) above sea level, which is in general agreement in elevation and correlation with the older Scotts Corners Formation.

Geologic History and Paleogeographic Reconstructions

Given the proposed correlations of the middle to late Pleistocene stratigraphic units, paleogeographic reconstructions are presented for the time of deposition of the older Lynch Heights, Omar, and Turtle Branch Formations and for the time of deposition of the younger Scotts Corners, Sinepuxent and Kent Island Formations. These reconstructions and the geologic history are based on interpretation of depositional environments of samples from core holes, soil auger borings, and limited outcrop data. The reconstructions are highly generalized and are intended as a preliminary regional interpretation of the geologic history of the interglacial deposits.

The surfaces of the older (higher terrace) Lynch Heights Formation and the Omar Formation form essentially a flat plain with an elevation of approximately 40 feet above sea level. The plain extends from the Maryland-Delaware southern border to north of Milford, Del., where the outcrop area of the Lynch Heights Formation narrows in width. The lateral boundary between the Lynch Heights and Omar Formations is somewhat arbitrary even though shown as a line in Figure 2. The relationship between the Lynch Heights and Omar Formations (Fig. 29A, B) is comparable to the relationship between the modern-day Delaware Atlantic and Delaware Bay depositional systems (Kraft et al., 1987). Barrier, lagoon, and marsh deposits along the Atlantic Coast grade to marsh, shoreline, and estuarine deposits along the Delaware Bay Coast.

During sea-level rise associated with interglacials MIS 11 and MIS 9 (400,000 and 320,000 yrs B.P., respectively), an open water muddy lagoon received deposits that are now a part of the Omar Formation (Owens and Denny, 1979a) and Lynch Heights Formation (Fig. 29A, B). These lagoons were located in drowned paleovalleys similar to the modern Rehoboth and Indian River Bays (Kraft et al., 1987).

With continued sea-level rise, the paleovalley was filled with sediment and the lagoonal deposits of the Lynch Heights Formation in the vicinity of Rehoboth Beach were overtopped by sandy tidal flat, washover, and dune deposits (Fig. 29C). These sandy deposits become thinner to the west where they interfinger with shoreline deposits. Likewise, the lagoonal deposits of the Omar Formation were overtopped by sandy shoreline and nearshore deposits that thin to the west. The transition zone between the Lynch Heights and Omar Formations is primarily a mix of reworked Beaverdam Formation sands with interspersed lenses of intertidal and estuarine mud, shallow subtidal sands and gravels, and some remnants of dune sands scattered on the land surface.

On the western side of the Delmarva Peninsula, contemporaneous with the Lynch Heights and Omar Formations, estuarine deposition was occurring in the ancestral Nanticoke River basin (Fig. 29A-C). Deposits include fine sand, silt, and clay with scattered oyster bioherms. A linear belt of sediment mapped as an extension of the Turtle Branch Formation trends parallel to the Nanticoke River and its tributary, Deep Creek, and crosses the present interfluve of the Delmarva Peninsula between the drainage basins of the Chesapeake and Delaware Bays north of Georgetown (shoreline deposits of Jordan, 1974). This belt of sediment continues across to the vicinity of Sand Hill where it connects with the Lynch Heights Formation. It is possible that during the maximum MIS 11 highstand there may have been a small connection between the upper reaches of the Nanticoke River and Delaware Bay. Global sea level was high enough during MIS 11 (+20 m, >60 ft) (van Hengstum, et al., 2009) to have made the connection across the Delmarva interfluve, but it is unknown what relative sea level in the local area was during the interglacial. Further detailed geologic mapping is needed to confirm this connection.

After deposition of the older Lynch Heights Formation, there was a sea-level drop and then another rise that produced deposition in the younger Lynch Heights Formation during MIS 9 (330,000 yrs B.P.). During this event, sediments comprising the younger Lynch Heights Formation were deposited in nearshore and shallow offshore deposits. In the vicinity of what is now Rehoboth Beach, muddy sediments were deposited in a lagoon (Fig. 29B) which is mapped as the younger Lynch Heights Formation. Open-water estuarine deposition was present in the vicinity of the modern Pepper Creek, now mapped with the Omar Formation. Both of the lagoon and estuarine deposits were overridden by nearshore and shallow-water deposition during the highstand associated with MIS 9 (Fig. 29C).

As in the deposition of the older Lynch Heights deposits, there was estuarine deposition along the ancestral Nanticoke River, which was restricted to the lower Nanticoke south of Seaford. There are subtle breaks in topography that indicate shoreline erosion of the deposits of the older Turtle Branch Formation. It is not possible to separate the older and younger Turtle Branch Formation into discrete units. It is unknown whether the estuarine mud with oyster shells that underlies the younger Turtle Branch Formation terrace is a separate phase of deposition or is an extension of the older Turtle Branch Formation that was not removed by erosion.

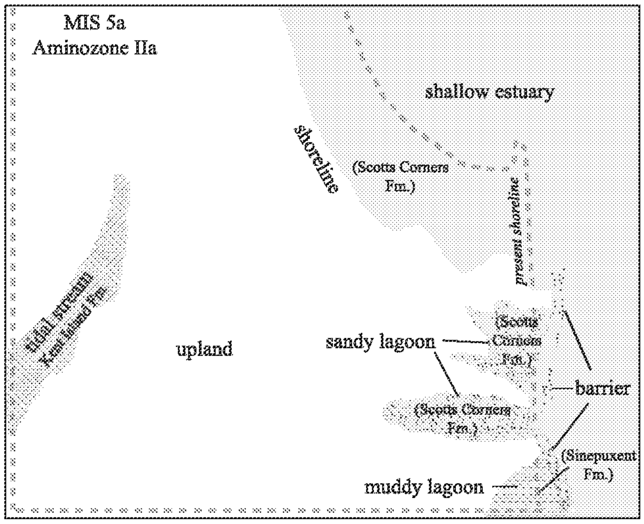

Figure 30. Conceptual model of high-stand depositional environments during the time of despositions of the Scotts Corners, Sinepuxent, and Kent Island Formations. The environments are much like that of today with lagoonal deposits along the ancestral Atlantic Coast, shallow estuarine environments along the ancestral Delaware Bay coast, and tidal stream deposits along the ancestral Nanticoke River. Dashed line represents the present Delaware/Maryland state boundary and the Atlantic Coast.

After deposition of the Lynch Heights, Omar, and Turtle Branch Formations, sea level again fell and rose during MIS 7 (240,000-220,000 yrs B.P.). It is possible that during this period and/or during the subsequent glacial period, deep incision produced stream networks that are antecedent to present stream networks. Valleys in the Coastal Plain were carved by the streams adjusting to the sea-level low, and the Delaware River was fed from the continental glacial margins in Pennsylvania and New York. Illinoian glacial deposits occur in Pennsylvania and New York in the Delaware and Susquehanna drainage basins (Fig. 3) (Braun, 2008).

With the subsequent rise in sea level as the continental ice sheet melted, deposition occurred during MIS 5e (120,000 yrs B.P.) along the margins of an ancestral Delaware Bay to form what is now recognized as the older Scotts Corners Formation. Along the Atlantic Coast, south of a headland at Rehoboth Beach, the Ironshire Formation was deposited in barrier and nearshore deposits. Along the ancestral Nanticoke River, the Kent Island Formation was deposited as swamp, marsh, and tidal stream deposits.

The final phase (prior to the Holocene) of Coastal Plain deposition in Delaware occurred during MIS 5a (Fig. 30). Along the Delaware Bay Coast, scattered deposits of the younger Scotts Corners Formation are found seaward of a very subtle scarp (toe of the scarp is at approximately 7 feet in elevation) (Fig. 5). Along the Atlantic Coast, a barrier-back barrier system developed in which the Sinepuxent Formation was deposited (Figs. 2, 9, 30). Along the Nanticoke River, there may have been additional estuarine deposits that are mapped with the Kent Island Formation that occur along the river to the south of Seaford at elevations at about 5 feet or less.

CONCLUSIONS

The history of the Coastal Plain of Delaware records the rise and fall of sea level during multiple interglacial and glacial periods. The interglacial periods resulted in deposition during rising sea level and at sea-level highstands that are now recognized as deposits of the Delaware Bay, Assawoman Bay, and Nanticoke River Groups. Each of these groups consists of heterogeneous lithologies deposited in stream to nearshore depositional systems. The Delaware Bay Group consists of the Lynch Heights and Scotts Corners Formations that represent deposition in estuarine and nearshore environments marginal to an ancestral Delaware Bay. The Assawoman Bay Group consists of the Omar, Ironshire, and Sinepuxent Formations that represent deposition in nearshore, estuarine, and lagoonal depositional environments marginal to the Atlantic Ocean. The Nanticoke River Group consists of the Turtle Branch and Kent Island Formations that represent deposition in swamp to estuarine depositional environments. The Lynch Heights, Omar, and Turtle Branch Formations are considered to be age equivalent and are thought to be about 400,000 to 325,000 yrs B.P. (MIS 11 and 9, respectively). The older Scotts Corners, Ironshire, and Kent Island Formations are considered to be age equivalent and are thought to be about 120,000 yrs B.P. (MIS 5e). The younger Scotts Corners and Sinepuxent Formations, and perhaps part of the Kent Island Formations, are considered to be age equivalent and are thought to be about 80,000 yrs B.P. (MIS 5a).

The older Lynch Heights, Omar, and Turtle Branch Formations are considered to be correlative (Fig. 28). They have similar land surface elevations, drainage network characteristics, and samples from the Lynch Heights Formation and Omar Formation yield aminozone IId ratios. The Lynch Heights and Omar Formations have also yielded samples that occur in aminozones IIc and IId; therefore, they are composite units. The two components are geomorphically distinct in the Delaware Bay Group (the older and younger Lynch Heights Formation) but are not as geomorphically distinct within the Omar Formation. The Lynch Heights and Omar Formations are physically contiguous (Figs. 2, 25) with no geomorphic indications of a break between the units. Both units also contain well-developed lagoonal deposits that fill incised paleovalleys (Owens and Denny, 1979a) that are perpendicular to the present coastline. The lagoonal deposits of the Omar Formation are assigned to aminozone IId. The lagoonal deposits of the Lynch Heights Formation appear to be younger, with ratios assigned to aminozone IIc.

The composite nature of the Turtle Branch Formation and correlation with the Lynch Heights and Omar Formations is tenuous (Fig. 28). The range of land surface elevations is similar. There are no amino-acid racemization data from the Turtle Branch Formation other than one sample with a tenuous location, which had shells that yielded aminozone IIc. The Turtle Branch Formation is older than the Kent Island Formation, which has yielded samples with aminozone IIa or IIb ratios, thus the Turtle Branch Formation likely correlates with aminozone IIc or IId. Based on the geomorphic evidence and the fact that the Turtle Branch Formation is older than the Kent Island Formation, the Turtle Branch Formation is considered to be correlative with the Lynch Heights and Omar Formations. Further work and amino-acid racemization data are needed to confirm this correlation.

The older Scotts Corners and the Ironshire Formations are considered to be correlative (Fig. 28). They lie beneath similar land surface elevations and have similar stream networks (although that of the Ironshire is limited) and are bracketed stratigraphically by deposits that yielded shells with aminozone IIc and IIa ratios. The Kent Island Formation is also considered to be correlative to these units for the same geomorphic characteristics. The only aminozone assignment is from the Kent Island, which is either IIa or IIb.

The younger Scotts Corners and the Sinepuxent Formations are considered to be correlative based on geomorphic characteristics (Table 5, Fig. 28). The Sinepuxent Formation yielded samples that are assigned to aminozone IIa. No shells have been collected from the younger Scotts Corners Formation. The limited pollen data do not support this correlation between these two units; further collection of pollen-yielding samples from the younger Scotts Corners Formation is needed. It is possible that portions of the Kent Island Formation are also correlative to these units where a low terrace is found along the Nanticoke River.

Future work should strengthen correlations of the lithostratigraphic units with the MIS record as more age-dateable material becomes available. Palynologic analysis may determine if the climatic signal of pollen records from the stratigraphic units can be correlated to climatic signals (warmer or cooler) related to specific MIS events. Finally, regional correlation may help us to better understand the relationship of the stratigraphic units described in this report with those of adjacent states to develop a regional history of the middle to late Pleistocene.

REFERENCES CITED

Andres, A. S., 2004, The Cat Hill Formation and Bethany Formation of Delaware: Delaware Geological Survey Report of Investigations No. 67, 8 p.

Andres, A.S., and Howard, C.S., 2000, The Cypress Swamp Formation, Delaware: Delaware Geological Survey Report of Investigations No. 62, 13 p.

Andres, A.S., and Klingbeil, A.D., 2006, Thickness and transmissivity of the unconfined aquifer of eastern Sussex County, Delaware: Delaware Geological Survey Report of Investigations No. 70, 19 p.

Andres, A.S., and Ramsey, K.W., 1995, Geologic Map of the Seaford area, Delaware: Delaware Geological Survey Geologic Map Series No. 9, scale 1:24,000.

______, 1996, Geology of the Seaford area, Delaware: Delaware Geological Survey Report of Investigations No. 53, 22 p.

Andres, A.S., Ramsey, K.W., and Schenck, W.S., 1995, Basic data for the geologic map of the Seaford area, Delaware: Delaware Geological Survey Open File Report No. 39, 39 p.

Ashton, N., Lewis, S.G., Parfitt, S.A., Penkman, K.E.H., and Coope, G.R., 2008, New evidence for complex climate change in MIS 11 from Hoxne, Suffolk, UK: Quaternary Science Reviews, v. 27, p. 652-668.

Bard, E., Antonioli, F., and Silenzi, S., 2002, Sea-level during the penultimate interglacial period based on a submerged stalagmite from Argentarola Cave (Italy): Earth and Planetary Science Letters, v. 196, p. 135-146.

Belknap, D.F., 1979, Application of amino-acid geochronology to stratigraphy of the late Cenozoic marine units of the Atlantic Coastal Plain: unpublished Ph.D. dissertation, University of Delaware, Newark, 550 p.

Bintanja, R., van de Wal, R.S.W., and Oerlemans, J., 2005, Modelled atmospheric temperatures and global sea levels over the past million years: Nature v. 437, p. 125-128.

Bowen, D.Q., 1978, Quaternary Geology: Oxford, U.K., Pergamon Press, 221 p.

Braun, D., 2008, The Pleistocene record in the middle and lower Susquehanna River Basin and the longer term evolution of the Susquehanna Basin landscape: Guidebook for the 20th Biennial Meeting of the American Quaternary Association, 58 p.

Chappell, J., Omura, A., Esat, T., McCulloch, M., et al., 1996, Reconciliation of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep sea oxygen isotope records: Earth and Planetary Science Letters, v. 141, p. 227-236.

Colman, S.M., and Mixon, R.B., 1988, The record of major Quaternary sea-level changes in a large coastal plain estuary, Chesapeake Bay, eastern United States: Paleogeography, Paleoclimatology, Paleoecology, v. 68, p. 99-116.

Cutler, K.B., Edwards, R.L., Taylor, F.W., Cheng, H., et al., 2003, Rapid sea-level fall and deep ocean temperature change since the last interglacial period: Earth and Planetary Letters v. 206, p. 253-271.

Demarest, J.M., II, 1981, Genesis and preservation of Quaternary paralic deposits on Delmarva Peninsula: unpublished Ph.D. dissertation, University of Delaware, Newark, 240 p.

Dowsett, H.J., and Wiggs, L.B., 1992, Planktonic foraminiferal assemblage of the Yorktown Formation, Virginia, U.S.A.: Micropaleontology, v 38, p. 75-86.

Droxler, A.W., and Farrell, J.W., 2000, Marine isotope stage 11 (MIS 11): new insights for a warm future: Global and Planetary Change, v. 24, p. 1-5.

Groot, J.J., 1991, Palynological evidence for late Miocene, Pliocene, and early Pleistocene climate changes in the Middle U.S. Atlantic Coastal Plain: Quaternary Science Reviews, v. 10, p. 147-162.

Groot, J.J., Benson, R.N., and Wehmiller, J.F., 1995, Palynological, foraminiferal, and aminostratigraphic studies of quaternary sediments from the U.S. Middle Atlantic Upper continental slope, continental shelf and coastal plain: Quaternary Science Reviews, v. 14, p. 17-49.

Groot, J.J. and Jordan, R.R., 1999, The Pliocene and Quaternary deposits of Delaware: palynology, ages, and paleoenvironments: Delaware Geological Survey Report of Investigations No. 58, 36 p.

Groot, J.J., Ramsey, K.W., and Wehmiller, J.F., 1990, Ages of the Bethany, Beaverdam, and Omar Formations of southern Delaware: Delaware Geological Survey Report of Investigations No. 47, 19 p.

Hansen, H.J., 1966, Pleistocene stratigraphy of the Salisbury area, Maryland and its relationship to the lower Eastern Shore: a subsurface approach: Maryland Geological Survey Report of Investigations No. 2, 56 p.

Hearty, P.J., 2002, Revision of the late Pleistocene stratigraphy of Bermuda: Sedimentary Geology, v. 153, p. 1-21.

Hearty, P.J., and Kaufman, D., 2000, Whole-rock aminostratigraphy and Quaternary sea-level history of the Bahamas: Quaternary Research, v. 54, p. 163-173.

Hobbs, C.H., III, 2004, Geological history of Chesapeake Bay, USA: Quaternary Science Reviews, v. 23, p. 641-661.

Jordan, R.R., 1962, Stratigraphy of the sedimentary rocks of Delaware: Delaware Geological Survey Bulletin No. 9, 51 p.

______, 1964, Columbia (Pleistocene) sediments of Delaware: Delaware Geological Survey Bulletin No. 12, 69 p.

______, 1974, Pleistocene deposits of Delaware, *in* Oaks, R.Q., and DuBar, J.R., eds., Post-Miocene stratigraphy central and southern Atlantic Coastal Plain: Logan, Utah, Utah State University Press, p. 30-52.

Kraft, J.C., Chrzastowski, M.J., Belknap, D.F., Toscanco, M.A., and Fletcher, C.H., III, 1987, The transgressive barrier-lagoon coast of Delaware: morphostratigraphy, sedimentary sequences and responses to relative rise in sea level: Society of Economic Geologists and Paleontologists (SEPM) Special Publication 41, p 129-143.

Lambeck, K., Yokoyama, Y, and Purcell, T., 2002, Into and out of the Last Glacial Maximum: sea-level change during Oxygen Isotope Stages 3 and 2: Quaternary Science Reviews, v. 21, p. 343-360.

Lisiecki, L.E., and Raymo, M.E., 2005, A Pliocene-Pleistocene stack of 57 globally distributed benthic $\Delta^{18}O$ records: Paleoceanography, v. 20, PA1003, doi: 10.1029/2004PA001071.

Mallinson, D., Burdette, K., Mahan, S., and Brook, G., 2008, Optically stimulated luminescence age controls on late Pleistocene and Holocene coastal lithosomes, North Carolina, USA: Quaternary Research v 69, p. 97-109.

Markewich, H.W., Litwin, R.J., Pavich, M.J., and Brook, G.A., 2009, Late Pleistocene eolian features in southeastern Maryland and Chesapeake Bay region indicate strong WNW-NW winds accompanied growth of Laurentide Ice Sheet: Quaternary Research v. 71, p. 409-425.

ED_005024_00000664-00043

McDonald, K.A., 1981, Three-dimensional analysis of Pleistocene and Holocene coastal sedimentary units at Bethany Beach, Delaware: unpublished M.S. Thesis, University of Delaware, Newark, 205 p.

McGee, W.J., 1886, Geological formations underlying Washington and vicinity: American Journal of Science, 3rd series, v. 31, p. 7473-474.

McLaughlin, P.P., Miller, K.M., Browning, J.V., Ramsey, K.W., et al., 2008, Stratigraphy and correlation of the Oligocene to Pleistocene section at Bethany Beach, Delaware: Delaware Geological Survey Report of Investigations No. 75, 41 p.

Miller, K.G., McLaughlin, P.P., Browning, J.V., Benson, R.N., et al., 2003, Bethany Beach Site, *in* Miller, K.G., Sugarman, P.J., Browning, J.V., et al., Proceedings ODP Initial Reports, 174AX (Suppl.), p. 1-85.

Mirecki, J.E., Wehmiller, J.F., and Skinner, A., 1995, Geochronology of Quaternary coastal units, southeastern Virginia: Journal of Coastal Research, v. 11, p. 1135-1144.

Mixon, R.B., 1985, Stratigraphic and geomorphic framework of uppermost Cenozoic deposits in the Southern Delmarva Peninsula, Virginia and Maryland: U.S. Geological Survey Professional Paper 1067-G, 53 p.

Mixon, R.B., Berquist, C.R., Jr., Newell, W.L., Johnson, G.H., et al., 1989, Geologic map and generalized cross sections of the Coastal Plain and adjacent parts of the Piedmont, Virginia: U.S. Geological Survey Miscellaneous Investigations Series Map I-2033, scale 1:250,000.

Newell, W.L., and Clark, I., 2008, Geomorphic map of Worcester County, Maryland, interpreted from a LIDAR-based digital elevation model: U.S. Geological Survey Open File Report 2008-1005, 34 p.

Newell, W.L., Powars, D.S., Owens, J.P., and Schindler, J.S. 2001, Surficial geologic map of central and southern New Jersey: U.S. Geological Survey Miscellaneous Investigation Series Map I-2540-D, scale 1:100,000.

Oaks, R.Q., Jr., and DuBar, J.R., 1974, Introduction, *in* Oaks, R.Q., and DuBar, J.R., eds., Post-Miocene stratigraphy central and southern Atlantic Coastal Plain: Logan, Utah, Utah State University Press, p. 3-8.

Oertel, G.F., and Foyle, A.M., 1995, Drainage displacement by sea-level fluctuation at the outer margin of the Chesapeake Seaway: Journal of Coastal Research, v. 11, p. 583-604.

O'Neal, M.L., and McGeary, S., 2002, Late Quaternary stratigraphy and sea-level history of the northern Delaware Bay margin, southern New Jersey, USA: a ground penetrating radar analysis of composite Quaternary coastal terraces: Quaternary Science Reviews, v. 21, p. 929-946.

Owens, J.P., and Denny, C.S., 1978, Geologic map of Worcester County: Maryland Geological Survey County Geologic Map, scale 1:62,500.

_____, 1979a, Upper Cenozoic deposits of the Central Delmarva Peninsula, Maryland and Delaware: U.S. Geological Survey Professional Paper 1067-A, 28 p.

_____, 1979b, Geologic map of Wicomico County: Maryland Geological Survey County Geologic Map, scale 1:62,500.

Ramsey, K.W., 1992, Coastal response to late Pliocene climate change: middle Atlantic Coastal Plain, Virginia and Delaware, in Fletcher, C.H., and Wehmiller, J.F., eds., Quaternary coasts of the United States: marine and lacustrine systems: Society of Economic Paleontologists and Mineralogists (SEPM) Special Publication No. 48, p. 121-127.

_____, 1993, Geologic map of the Milford and Mispillion River quadrangles: Delaware Geological Survey Map Series No. 8, scale 1:24,000.

_____, 1997, Geology of the Milford and Mispillion River Quadrangles: Delaware Geological Survey Report of Investigations No. 55, 40 p.

_____, 2001, Geologic map of the Milton and Ellendale Quadrangles, Delaware: Delaware Geological Survey Geologic Map Series No. 11, Scale 1:24,000.

_____, 2003, Geologic Map of the Lewes and Cape Henlopen quadrangles, Delaware: Delaware Geological Survey Map Series No. 12, scale 1:24,000.

_____, 2005, Geologic Map of New Castle County, Delaware: Delaware Geological Survey Geologic Map Series No. 13, scale 1:100,000.

_____, 2007, Geologic Map of Kent County, Delaware: Delaware Geological Survey Geologic Map Series No. 14, scale 1:100,000.

_____, 2010, Geologic Map of the Georgetown Quadrangle, Delaware: Delaware Geological Survey Geologic Map Series No. 15, scale 1:24,000.

Ramsey, K.W., and Baxter, S.J., 1996, Radiocarbon dates from Delaware: a compilation: Delaware Geological Survey Report of Investigations No. 54, 18 p.

Rasmussen, W.C., and Slaughter, T.H., 1955, The ground-water resources of Somerset, Wicomico, and Worcester Counties: Maryland Department of Geology, Mines, and Water Resources Bulletin 16, 535 p.

Richmond, G.M., and Fullerton, D.S., 1986, Summary of Quaternary glaciations in the United States of America, *in* Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary glaciations in the northern Hemisphere, p. 183-200.

Ritter, D.F., 1978, Process Geomorphology: Dubuque, Iowa, Wm. C. Brown Company Publishers, 603 p.

Spoljaric, N., 1967, Pleistocene channels of New Castle County, Delaware: Delaware Geological Survey Report of Investigations No. 10, 15 p

Spoljaric, N. and Woodruff, K.D., 1970, Geology, hydrology, and geophysics of Columbia sediments in the Middletown-Odessa area, Delaware: Delaware Geological Survey Bulletin No. 13, 156 p.

Stanford, S.D., 1997, Pliocene-Quaternary geology of Northern New Jersey: an overview, *in*, Stanford, S.D., and Witte, R.W. eds., Pliocene-Quaternary Geology of Northern New Jersey: Guidebook for the 60th Annual Reunion of the Northeastern Friends of the Pleistocene, p. 1-1 to 1-26.

Tzedakis, P.C., Andrieu, V., de Beaulieu, J.-L., Birks, H.J.B., et al., 2001, Establishing a terrestrial chronological framework as a basis for biostratigraphical comparisons: Quaternary Science Reviews, v. 20, p. 1583-1592.

van Hengstum, P.J., Scott, D.B., and Javaux, E.J., 2009, Foraminifera in elevated Bermudian caves provide further evidence for +21 m eustatic sea level during Marine Isotope Stage 11: Quaternary Science Reviews, v. 28, p. 1850-1860.

Weems, R.E., and Lewis, W.C., 2007, Detailed sections from auger holes in the Roanoke Rapids 1:100,000 sheet, North Carolina: U.S. Geological Survey Open File Report No. 2007-1092, 135 p.

Walker, J.D., and Geissman, J.W., compilers, 2009, Geologic Time Scale: Geological Society of America, doi: 10.1130/2009.CTS004R2C.

Walker, M., Johnsen, S., Rasmussen, S.O. et al., 2009, Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records: Journal of Quaternary Science, v. 24, p. 3-17.

Walker, M., and Lowe, J., 2007 Quaternary science 2007: a 50-year retrospective: Journal of the Geological Society of London, v. 164, p. 1073-1092.

Wehmiller, J.F., Belknap, D.F., Boutin, B.S., Mirecki, J.E., et al., 1988, A review of the aminostratigraphy of Quaternary mollusks from United States Atlantic Coastal Plain sites, *in* Easterbrook, D.L., ed., Dating Quaternary sediments: Geological Society of America Special Paper 227, pp. 69-110.

Wehmiller, J.F., Simmons, K.R., Cheng, H., Edwards, R.L., et al., 2004, Uranium-series coral ages from the US Atlantic Coastal Plain-the "80 ka problem" revisited: Quaternary International, v. 120, p. 3-14.

White, W. A., 1979, Influence of glacial meltwater in the Atlantic Coastal Plain: Southeastern Geology, v. 19, p. 139-156.

Williams, C.P., 1999, Late Pleistocene and Holocene stratigraphy of the Delaware inner continental shelf: unpublished M.S. Thesis, University of Delaware, Newark, 175 p.

Wright, J.S., 2007, An overview of the role of weathering in the production of quartz silt: Sedimentary Geology, v. 202, p. 337-351.

APPENDIX: Summary of Pollen Data for Stratigraphic Units

Formation	DGSID	Sample#	Northing	Easting	Depth (ft)	Land Surface Elev. (ft)	Sample Elev. (ft)	Dep Env.	Climate	Arboreal Components	Comments	Reference
LYNCH HEIGHTS FORMATION	Le14-18	25706-2	4316084.3	461924.0	20	28	8	Marsh?	Warm	Pinus-Quercus-Carya		A
	Le14-18	25707-1	4316084.3	461924.0	22	28	6	Marsh?	Temp	Pinus-Quercus-Carya		A
	Le14-18	25707-2	4316084.3	461924.0	23	28	5	Marsh?	Warm	Pinus-Quercus-Carya		A
	Le14-a	41373	4315603.0	462060.4	18	20	2	Freshwater marsh	Temp	Quercus-Pinus		A
	Le25-12	25639	4313611.5	463071.8	11.5	30	18.5	Estuarine	Cool temp	Pinus dominant	Few Picea	A
	Le44-09*	85436	4309887.4	461560.1	13	41	28	Estuarine	Cool temp	Pinus-Quercus-Betula	Few Picea	A
	Le44-09*	85439	4309887.4	461560.1	22.5	41	18.5	Marsh?	Cool temp	Pinus-Betula-Quercus	Few Picea	A
	Lf21-19	25627	4313848.5	464370.5	14.5	30	15.5	Estuarine	Cool temp	Pinus-NAP-Quercus	Few Picea	A
	Ng45-01*	87465	4292534.8	477907.2	12.5	16	3.5	Marsh	Cool temp	Quercus-Pinus-Picea		A
	Ng45-01*	87466	4292534.8	477907.2	15	16	1	Marsh	Cool temp	Quercus-Pinus-Picea		A
	Ng45-01*	87467	4292534.8	477907.2	13.5	16	-2.5	Marsh	Cool temp	Pinus-Quercus-Picea		A
	Nh44-a*	41142	4291371.8	482770.0	8.5	15	6.5	Estuarine	Temp	Quercus-Betula-Pinus		A
	Nh45-02*	25044	4291282.4	485264.3	15	9	-6	Estuarine	Temp	Quercus-Pinus		A
SCOTTS CORNERS FORMATION	Lf13-a	40975	4315363.5	467281.4	9	11	2	Marsh	Warm	Pinus-Quercus-Betula		A
	Lf14-a	40976	4315017.5	469203.6	7.5	7.5	0	Estuarine	Warm	Pinus-Quercus-Alnus		A
	Lf14-b	41323	4315976.0	468413.8	5.75	8	2.25	Estuarine	Temp	Pinus-Quercus-Betula		A
	Lf14-c	41330	4316037.0	468679.0	7.5	6	-1.5	FW Marsh	Warm	Pinus-Quercus	1% Tsuga, Pinus dom	A
	Lf14-e	41334	4316221.0	468847.6	5.5	4	-1.5	Marsh	Warm	Pinus-Alnus-Quercus		A
	Lf14-j	41336	4315881.5	468870.7	6.5	5	-1.5	Marsh	Warm	Pinus-Quercus-Betula	1% Tsuga	A
	Lf14-m	41353	4315942.0	469279.9	7	3	-4	Marsh?	Warm	Pinus-Quercus-Carya	Pinus dom	A
	Lf14-n	41356	4316066.0	469063.7	8	4	-4	Marsh?	Warm	Pinus-Quercus-Carya	2% Tsuga, Pinus dom	A
	Lf14-p	41425	4315173.0	468892.3	8	8	0	?	Warm	Pinus-Quercus-Betula		A
	Lf14-p	41431	4315173.0	468892.3	10.5	8	-2.5	?	Temp	Pinus-Quercus-Tsuga	11% Tsuga	A
	Lf14-p	41435	4315173.0	468892.3	13.25	8	-5.25	?	Warm	Quercus-Pinus-Carya	3% Tsuga	A
	Lf21-b	41367	4314850.0	465041.1	9.5	18	8.5	Estuarine	Warm	Quercus-Pinus		A
	Lf23-ac	41482	4313696.0	468164.1	9	9.5	0.5	Estuarine	Warm	Pinus-Carya-Quercus	4% Tsuga	A
	Lf23-ac	41485	4313696.0	468164.1	11.5	9.5	-2	Estuarine	Warm	Quercus-Pinus-Liquidambar	6% Tsuga	A
	Lf23-ad	41489	4313976.0	467707.9	11	9	-2	Estuarine	Temp	Pinus-Carya-Quercus	Pinus dom	A
	Lf23-f	41344	4313514.0	467466.1	11.5	5	-6.5	?	Warm	Quercus-Pinus-TCT	13% TCT	A
	Lf23-u	41464	4313820.0	468069.4	7	10.5	3.5	Estuarine	Warm	Pinus-Quercus-Carya		A
	Lf23-x	41465	4313665.0	468189.1	2.25	9	6.75	?	Warm	Pinus-Quercus	6% Tsuga	A
	Lf23-x	41469	4313665.0	468189.1	8	9	1	Estuarine	Warm	Quercus-Pinus	6% Tsuga	A
	Lf23-x	41472	4313665.0	468189.1	9.25	9	-0.25	Estuarine	Warm	Quercus-Pinus-Liquidambar	2% Tsuga	A
	Lf24-02*	25659-1	4314199.4	469569.5	2	7	5	?	Warm	Pinus-Quercus		A
	Mg21-06*	25658-1	4305375.0	471149.9	3	10	7	Estuarine	Warm	Pinus-Quercus-Carya		A

*stratigraphic unit different from published unit
A = Groot and Jordan, 1999

APPENDIX (cont.)

Formation	DGSID	Sample#	Northing	Easting	Depth (ft)	Land Surface Elev. (ft)	Sample Elev. (ft)	Dep Env.	Climate	Arboreal Components	Comments	Reference
OMAR FORMATION	Qh34-09	85678	4266223.0	483886.1	6	16	10	Estuarine	Temp	Pinus-Quercus-Carya		A
	Qh34-09	85679	4266223.0	483886.1	10	16	6	Estuarine	Temp	Pinus-Quercus-Carya		A
	Qh35-04	85652	4266592.0	484298.4	23	14	-9	Lagoon	Warm	Pinus-Quercus-Carya-Liquidambar		A
	Qh35-08	85709	4266688.1	484176.1	13	15	2	Lagoon	Warm	Pinus-Alnus-Quercus		A
	Qh35-09	85711	4266041.0	484072.5	13	18	5	Lagoon	Warm	Pinus-Quercus		A
	Qh35-09	85713	4266041.0	484072.5	18	18	0	Marsh	Warm	Pinus-Alnus		A
	Qh41-a	40962	4264314.2	478496.3	6	18	12	Lagoon	Warm	Quercus-Betula-Pinus		A
	Qh44-01	20774.1	4264831.8	483345.9	40	22	-18	Fresh water	Warm	Pinus-Quercus-Carya		A
	Qh44-01	20775.2	4264831.8	483345.9	45	22	-23	Fresh water	Warm	Quercus-Carya-Nyssa-Pinus		A
	Qh44-01	20773.1	4264831.8	483345.9	36	22	-14	Fresh water	Warm	Pinus-Quercus-Carya		A
	Qh44-01	20765	4264831.8	483345.9	3	22	19	Estuarine	Warm	Pinus-Carya	Pinus dom	A
	Qh44-01	20767.6	4264831.8	483345.9	13.8	22	8.2	Marsh	Temp	Pinus-Alnus-Quercus-Carya		A
	Qh44-01	20766	4264831.8	483345.9	9	22	13	Fresh water	Temp	Pinus-Alnus-Myrica		A
	Qh44-01	20768.2	4264831.8	483345.9	16	22	6	Swamp	Temp	Carya-Carpinus-Nyssa-Quercus		A
	Qh44-01	20769	4264831.8	483345.9	21	22	1	Fresh water	Cool-Cold	Pinus-Picea		A
	Qh44-01	20772.2	4264831.8	483345.9	34	22	-12	Swamp	Temp	TCT-Pinus-Betula		A
	Qh44-01	20771.1	4264831.8	483345.9	28	22	-6	Swamp	Temp	Pinus-Quercus-Alnus-Carya		A
	Qi51-04	25046	4262588.6	486181.8	10	21	11	Lagoon	Temp	Pinus-Quercus		A
	Qi51-04	25047	4262588.6	486181.8	30	21	-9	Lagoon	Temp	Pinus-Quercus		A
	Qi51-04	25049	4262588.6	486181.8	55	21	-34	Lagoon	Temp	Pinus-Quercus		A
	Qi51-04	25050	4262588.6	486181.8	85	21	-64	Lagoon	Temp	Pinus-Quercus-Carya-Alnus		A
	Qj32-27	26847	4266706.0	494503.0	34.4	4.6	-29.8	Lagoon	Warm	Pinus-Quercus		B,C
	Qj32-27	26848	4266706.0	494503.0	40.9	4.6	-36.3	Lagoon	Warm	Pinus-Quercus		B,C
	Qj32-27	26848	4266706.0	494503.0	45.8	4.6	-41.2	Lagoon	Warm	Pinus-Quercus		B,C
	Ri13-a	40969	4260854.3	488447.7	10	15	5	Lagoon/Marsh	Cool temp	Pinus-Quercus		A
IRONSHIRE FORMATION	Ri31-04	82894	4256540.0	486411.5	11	7	-4	Estuarine	Temp	Quercus-Pinus		B
	Ri31-a	41004	4256465.5	486403.7	7	16	9	Estuarine	Temp	Pinus-Quercus		B
SINEPUXENT FORMATION	Qi55-09	102283	4262551.9	492709.3	23.45	5	-18.45	Estuarine	Cool	Pinus-Alnus-Picea		B
	Qi55-09	102284	4262551.9	492709.3	25.5	5	-20.5	Estuarine	Cool	Pinus-Alnus-Picea		B
	Qj32-27	26843	4266706.0	494503.0	8	4.6	-3.4	Estuarine	Cool temp	Pinus- Picea-Betula		B,C
	Qj32-27	26845	4266706.0	494503.0	16.4	4.6	-11.8	Estuarine	Cool temp	Pinus- Picea-Betula		B,C
	Qj32-27	26846	4266706.0	494503.0	24.5	4.6	-19.9	Estuarine	Cool temp	Pinus- Picea-Betula		B,C
	Ri34-13	102258	4256256.2	490947.8	15.8	6	-9.8	Estuarine	Cool	Pinus-Alnus-Picea		B

*stratigraphic unit different from published unit
A = Groot and Jordan, 1999; B=unpublished DGS data; C=McLaughlin et al., 2008

APPENDIX (cont.)

	DGSID	Sample#	Northing	Easting	Depth (ft)	Land Surface Elev. (ft)	Sample Elev. (ft)	Dep Env.	Climate	Arboreal Components	Comments	Reference
TURTLE BRANCH FORMATION**	Ob23-07	84847	4286791.5	438048.8	7	38	31	Estuarine	Temp	Pinus-Quercus		D
	Od11-b	42177	4288887.5	449332.4	4.5	30	25.5	?	Temp	Quercus-Alnus		D
	Od32-04	83186	4284666.0	451123.9	4	30	26	?	Temp	Pinus	Pinus dom	D
	Od32-c	42199	4284529.5	451092.4	6	32	26		Warm	Pinus-Quercus		A
	Od43-a3	41495	4283131.4	452290.5	14	36	22	Estuarine	Temp	Pinus-Quercus	Pinus dom	A
	Od51-04	84768	4281124.0	450642.9	17	27	10	Fluvial	Temp	Pinus-Quercus	Pinus dom	D
	Od51-04	84769	4281124.0	450642.9	19	27	8	Fluvial	Temp	Pinus-Quercus		D
	Od51-04	84770	4281124.0	450642.9	20.5	27	6.5	Freshwater Marsh	Temp	Pinus-Quercus		D
	Od51-04	84771	4281124.0	450642.9	23.5	27	3.5	Fluvial	Warm	Quercus-Pinus		D
	Pb34-04	84098	4275861.0	440406.5	11	36	25	Estuarine	Temp	Pinus	Pinus dom	A
	Pb34-04	84099	4275861.0	440406.5	13	36	23	Freshwater	Temp	Pinus-Quercus	Pinus dom	D
	Pb34-04	84101	4275861.0	440406.5	16	36	20	?		Pinus	Pinus dom	D
	Pb34-04	84104	4275861.0	440406.5	25	36	11	Estuarine	Temp	Pinus	Pinus dom	D
	Pb44-03	102013	4272699.1	440097.3	8.2	33	24.8	?	Cool and wet	Pinus	Pinus dom	B
	Pb44-03	102018	4272699.1	440097.3	19.3	33	13.7	Estuarine	Warm	Pinus-Quercus-Carya		B
	Pb55-03	84658	4272157.5	440562.0	16	32	16	?	Temp	Pinus-Quercus		A
	Pc25-04	22792	4273225.0	442127.4	8.5	25.7	17.2	Estuarine	Temp	Quercus-Pinus		A
	Pc25-04	22793	4273225.0	442127.4	15.2	30	14.8	Estuarine	Warm	Pinus-Quercus-Betula		A
	Pc41-01	22782	4273225.0	442127.4	11.1	22.6	11.5	Fluvial?	Warm	Pinus-Quercus-Alnus	Pinus dom	A
	Pc41-a	41866	4274384.0	442468.3	26	17.5		?	Temp	Pinus	Pinus dom	A
	Qb14-05	101986	4269120.1	439293.9	19.5	17	-2.5	Estuarine	Warm	Pinus-Quercus-Carya		B
	Qb14-05	101990	4269120.1	439293.9	26	17	-9	Estuarine	Warm	Pinus-Quercus-Carya		B
	Qb14-06	102035	4270196.2	440034.9	22.3	25	2.7	Estuarine	?	Pinus-Quercus-Carya		B
	Qb14-06	102044	4270196.2	440034.9	41.6	25	-16.6	Marsh	?	Graminae-Pinus		B
	Qc24-06	22774	4267553.0	447121.9	17	29	12	Fluvial?	Warm	Quercus-Pinus	Quercus dom	A
KENT ISLAND FORMATION**	Pc51-01	22711	4272421.5	442872.5	9.7	6	-3.7	Estuarine	Warm	Quercus-Carya-Pinus	Quercus dom	A
	Pc51-01	22712	4272421.5	442872.5	15	6	-9	Fluvial	Warm	Quercus-Pinus-Carya	Quercus dom	A
	Pc51-01	22713	4272421.5	442872.5	20	6	-14	Estuarine	Warm	Quercus-Pinus-Carya		A
	Qb23-01	84431	4268720.5	438997.9	4	6	2	Estuarine	Warm	Pinus-Quercus-Carya		A
	Qb23-01	84434	4268720.5	438997.9	12	6	-6	Fluvial-Estuarine	Temp	Pinus-Quercus-Carya		A

**Turtle Branch and Kent Island Fm. samples published as "Nanticoke deposits"
*stratigraphic unit different from published unit.
A = Groot and Jordan, 1999; B=unpublished DGS data; D=Andres and Ramsey, 1996

ED_005024_00000664-00048

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